OMB Number: 4040-0001
Expiration Date: 06/30/2011

APPLICATION FOR FEDERAL ASSISTANCE
SF 424 (R&R)

3. DATE RECEIVED BY STATE:

State Application Identifier:

1. * TYPE OF SUBMISSION

☐ Pre-application ☒ Application ☐ Changed/Corrected Application

4. a. Federal Identifier: N00014

b. Agency Routing Identifier: 341 [Chrisey, Linda]

2. DATE SUBMITTED:

Applicant Identifier:

5. APPLICANT INFORMATION

*** Organizational DUNS:** 1539267120000

* Legal Name: University of Massachusetts Amherst

Department: c/o Grant & Contract Admin. Division: Research & Engagement

* Street1: Research Admin. Bldg.

Street2: 70 Butterfield Terrace

* City: Amherst County / Parish: Hampshire

* State: MA: Massachusetts Province:

* Country: USA: UNITED STATES * ZIP / Postal Code: 01003-9242

Person to be contacted on matters involving this application

Prefix: Ms. * First Name: Carol Middle Name:

* Last Name: Sprague Suffix:

* Phone Number: (413) 545-0698 Fax Number: 413-545-1202

Email: ogca@research.umass.edu

6. * EMPLOYER IDENTIFICATION *(EIN) or (TIN):* 043167352

7. * TYPE OF APPLICANT: H: Public/State Controlled Institution of Higher Education

Other (Specify):

Small Business Organization Type ☐ Women Owned ☐ Socially and Economically Disadvantaged

8. * TYPE OF APPLICATION:

☒ New ☐ Resubmission

☐ Renewal ☐ Continuation ☐ Revision

If Revision, mark appropriate box(es).

☐ A. Increase Award ☐ B. Decrease Award ☐ C. Increase Duration ☐ D. Decrease Duration

☐ E. Other (specify):

* Is this application being submitted to other agencies? Yes ☐ No ☒ What other Agencies?

9. * NAME OF FEDERAL AGENCY: Office of Naval Research

10. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER: 12.300

TITLE: Basic and Applied Scientific Research

11. * DESCRIPTIVE TITLE OF APPLICANT'S PROJECT:

Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires

12. PROPOSED PROJECT:

* Start Date: 01/01/2012 * Ending Date: 12/31/2014

*** 13. CONGRESSIONAL DISTRICT OF APPLICANT:** MA-001

14. PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR CONTACT INFORMATION

Prefix: Dr. * First Name: Derek Middle Name: R

* Last Name: Lovley Suffix:

Position/Title: Professor

* Organization Name: University of Massachusetts Amherst

Department: Microbiology Division:

* Street1: 203N Morrill IVN

Street2: 639 North Pleasant St

* City: Amherst County / Parish: Hampshire

* State: MA: Massachusetts Province:

* Country: USA: UNITED STATES * ZIP / Postal Code: 01003-9298

* Phone Number: 413-545-9651 Fax Number: 413-577-4660

* Email: dlovley@microbio.umass.edu

15. ESTIMATED PROJECT FUNDING

a. Total Federal Funds Requested	638,349.00
b. Total Non-Federal Funds	0.00
c. Total Federal & Non-Federal Funds	638,349.00
d. Estimated Program Income	0.00

16. * IS APPLICATION SUBJECT TO REVIEW BY STATE EXECUTIVE ORDER 12372 PROCESS?

a. YES ☐ THIS PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON:

DATE:

b. NO ☒ PROGRAM IS NOT COVERED BY E.O. 12372; OR

☐ PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW

17. By signing this application, I certify (1) to the statements contained in the list of certifications* and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances * and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious. or fraudulent statements or claims may subject me to criminal, civil, or administrative penalities. (U.S. Code, Title 18, Section 1001)

☒ *** I agree**

**** The list of certifications and assurances, or an Internet site where you may obtain this list, is contained in the announcement or agency specific instructions.***

18. SFLLL or other Explanatory Documentation

Add Attachment | Delete Attachment | View Attachment

19. Authorized Representative

Prefix: Ms. * First Name: Carol Middle Name:

* Last Name: Sprague Suffix:

* Position/Title: Associate Director Grants and Contracts

* Organization: University of Massachusetts

Department: c/o Grant & Contract Admin. Division: Research & Engagement

* Street1: Research Administration Building

Street2: 70 Butterfield Terrace

* City: Amherst County / Parish: Hampshire

* State: MA: Massachusetts Province:

* Country: USA: UNITED STATES * ZIP / Postal Code: 01003-9242

* Phone Number: 413-545-0698 Fax Number: 413-545-1202

* Email: OGCA@research.umass.edu

* Signature of Authorized Representative	* Date Signed
carol sprague	09/27/2011

20. Pre-application

Add Attachment | Delete Attachment | View Attachment

OMB Number: 4040-0001
Expiration Date: 06/30/2011

Previous Period

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 1

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 01/01/2012 *** End Date:** 09/30/2012 **Budget Period** 1

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	* Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Dr.	Derek	R	Lovley		PD/PI	(b) (4)		0.50		(b) (4)	(b) (4)	(b) (4)
2.	Dr.	Nikhil		Malvankar		coPI	(b) (4)	4.50			(b) (4)	(b) (4)	(b) (4)
3.													
4.													
5.													
6.													
7.													
8.													

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person (b) (4)

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1	Post Doctoral Associates	4.50			(b) (4)	(b) (4)	(b) (4)
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	**Total Number Other Personnel**					**Total Other Personnel**	(b) (4)

Total Salary, Wages and Fringe Benefits (A+B) (b) (4)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 1539267120000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry * Start Date: 01/01/2012 * End Date: 09/30/2012 Budget Period 1

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	

Additional Equipment: Add Attachment Delete Attachment View Attachment

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	4,000.00
2.	Foreign Travel Costs	
	Total Travel Cost	4,000.00

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	

RESEARCH & RELATED Budget {C-E} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 1

Next Period

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 01/01/2012 *** End Date:** 09/30/2012 **Budget Period 1**

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	18,750.00
2.	Publication Costs	2,000.00
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Postdoctoral Health Insurance	2,504.00
9.		
10.		
	Total Other Direct Costs	23,254.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	92,458.00

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	Direct Cost 1/1/12-6/30/12	58.50	61,638.00	36,058.00
2.	Direct Cost 7/1/12-9/30/12	59.00	30,820.00	18,184.00
3.				
4.				
	Total Indirect Costs			54,242.00

Cognizant Federal Agency DHHS, Micheal Stanco, 212-264-1823

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	146,700.00

J. Fee

	Funds Requested ($)

K. * Budget Justification BudgetJustification.pdf Add Attachment Delete Attachment View Attachment

(Only attach one file.)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

Previous Period

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 2

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 10/01/2012 *** End Date:** 09/30/2013 **Budget Period** 2

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	* Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Dr.	Derek	R	Lovley		PD/PI	(b) (4)		0.75		(b) (4)	(b) (4)	(b) (4)
2.	Dr.	Nikhil		Malvankar		coPI	(b) (4)	6.00			(b) (4)	(b) (4)	(b) (4)
3.													
4.													
5.													
6.													
7.													
8.													

9. **Total Funds requested for all Senior Key Persons in the attached file**

Total Senior/Key Person (b) (4)

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1	Post Doctoral Associates	6.00			(b) (4)	(b) (4)	(b) (4)
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	**Total Number Other Personnel**					**Total Other Personnel**	(b) (4)

Total Salary, Wages and Fringe Benefits (A+B) (b) (4)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 1539267120000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry * Start Date: 10/01/2012 * End Date: 09/30/2013 Budget Period 2

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	

Additional Equipment: Add Attachment Delete Attachment View Attachment

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	4,120.00
2.	Foreign Travel Costs	
	Total Travel Cost	4,120.00

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	

RESEARCH & RELATED Budget {C-E} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 2

Next Period

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 10/01/2012 *** End Date:** 09/30/2013 **Budget Period 2**

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	25,750.00
2.	Publication Costs	3,000.00
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Postdoctoral Health Insurance	3,438.00
9.		
10.		
	Total Other Direct Costs	32,188.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	132,040.00

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	Direct Cost 10/1/12 - 9/30/13	59.00	132,040.00	77,904.00
2.				
3.				
4.				
			Total Indirect Costs	77,904.00

Cognizant Federal Agency DHHS, Micheal Stanco, 212-264-1823

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	209,944.00

J. Fee

	Funds Requested ($)

K. * Budget Justification BudgetJustification.pdf Add Attachment Delete Attachment View Attachment

(Only attach one file.)

Previous Period

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 3

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 10/01/2013 *** End Date:** 09/30/2014 **Budget Period** 3

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	* Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Dr.	Derek	R	Lovley		PD/PI	(b) (4)		0.75		(b) (4)	(b) (4)	(b) (4)
2.	Dr.	Nikhil		Malvankar		coPI	(b) (4)	6.00			(b) (4)	(b) (4)	(b) (4)
3.													
4.													
5.													
6.													
7.													
8.													

9. **Total Funds requested for all Senior Key Persons in the attached file**

Total Senior/Key Person (b) (4)

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1	Post Doctoral Associates	6.00			(b) (4)	(b) (4)	(b) (4)
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	**Total Number Other Personnel**					**Total Other Personnel**	(b) (4)

Total Salary, Wages and Fringe Benefits (A+B) (b) (4)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 1539267120000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry * Start Date: 10/01/2013 * End Date: 09/30/2014 Budget Period 3

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	

Additional Equipment: Add Attachment Delete Attachment View Attachment

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	4,244.00
2.	Foreign Travel Costs	
	Total Travel Cost	4,244.00

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	

RESEARCH & RELATED Budget {C-E} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 3

Next Period

* ORGANIZATIONAL DUNS: 1539267120000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry * Start Date: 10/01/2013 * End Date: 09/30/2014 Budget Period 3

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	26,523.00
2. Publication Costs	3,090.00
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. Postdoctoral Health Insurance	3,541.00
9.	
10.	
Total Other Direct Costs	33,154.00

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	136,001.00

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	Direct Cost 10/1/13 - 9/30/14	59.00	136,001.00	80,241.00
2.				
3.				
4.				
			Total Indirect Costs	80,241.00

Cognizant Federal Agency DHHS, Micheal Stanco, 212-264-1823
(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	216,242.00

J. Fee	Funds Requested ($)

K. * Budget Justification BudgetJustification.pdf Add Attachment Delete Attachment View Attachment
(Only attach one file.)

Previous Period

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 4

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 10/01/2014 *** End Date:** 12/31/2014 **Budget Period** 4

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	* Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Dr.	Derek	R	Lovley		PD/PI	(b) (4)		0.25		(b) (4)	(b) (4)	(b) (4)
2.	Dr.	Nikhil		Malvankar		coPI	(b) (4)	1.50			(b) (4)	(b) (4)	(b) (4)
3.													
4.													
5.													
6.													
7.													
8.													

9. **Total Funds requested for all Senior Key Persons in the attached file**

Total Senior/Key Person (b) (4)

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1	Post Doctoral Associates	1.50			(b) (4)	(b) (4)	(b) (4)
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	**Total Number Other Personnel**					**Total Other Personnel**	(b) (4)

Total Salary, Wages and Fringe Benefits (A+B) (b) (4)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 4

* ORGANIZATIONAL DUNS: 1539267120000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry * Start Date: 10/01/2014 * End Date: 12/31/2014 Budget Period 4

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	

Additional Equipment: Add Attachment Delete Attachment View Attachment

D. Travel	**Funds Requested ($)**
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	2,000.00
2. Foreign Travel Costs	
Total Travel Cost	2,000.00

E. Participant/Trainee Support Costs	**Funds Requested ($)**
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

RESEARCH & RELATED Budget {C-E} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 4

Next Period

*** ORGANIZATIONAL DUNS:** 1539267120000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: University of Massachusetts Amh

Delete Entry *** Start Date:** 10/01/2014 *** End Date:** 12/31/2014 **Budget Period 4**

F. Other Direct Costs	**Funds Requested ($)**
1. Materials and Supplies	6,830.00
2. Publication Costs	2,000.00
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. Postdoctoral Health Insurance	912.00
9.	
10.	
Total Other Direct Costs	9,742.00

G. Direct Costs	**Funds Requested ($)**
Total Direct Costs (A thru F)	41,172.00

H. Indirect Costs

	Indirect Cost Type	**Indirect Cost Rate (%)**	**Indirect Cost Base ($)**	*** Funds Requested ($)**
1.	Direct Cost 10/1/14 - 12/31/14	59.00	41,172.00	24,291.00
2.				
3.				
4.				
			Total Indirect Costs	24,291.00

Cognizant Federal Agency DHHS, Micheal Stanco, 212-264-1823
(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	**Funds Requested ($)**
Total Direct and Indirect Institutional Costs (G + H)	65,463.00

J. Fee	**Funds Requested ($)**

K. * Budget Justification BudgetJustification.pdf Add Attachment Delete Attachment View Attachment
(Only attach one file.)

RESEARCH & RELATED BUDGET - Cumulative Budget

		Totals ($)
Section A, Senior/Key Person		(b) (4)
Section B, Other Personnel		(b) (4)
Total Number Other Personnel	4	
Total Salary, Wages and Fringe Benefits (A+B)		(b) (4)
Section C, Equipment		
Section D, Travel		14,364.00
1. Domestic	14,364.00	
2. Foreign		
Section E, Participant/Trainee Support Costs		
1. Tuition/Fees/Health Insurance		
2. Stipends		
3. Travel		
4. Subsistence		
5. Other		
6. Number of Participants/Trainees		
Section F, Other Direct Costs		98,338.00
1. Materials and Supplies	77,853.00	
2. Publication Costs	10,090.00	
3. Consultant Services		
4. ADP/Computer Services		
5. Subawards/Consortium/Contractual Costs		
6. Equipment or Facility Rental/User Fees		
7. Alterations and Renovations		
8. Other 1	10,395.00	
9. Other 2		
10. Other 3		
Section G, Direct Costs (A thru F)		401,671.00
Section H, Indirect Costs		236,678.00
Section I, Total Direct and Indirect Costs (G + H)		638,349.00
Section J, Fee		

BUDGET JUSTIFICATION
Office of Naval Research BAA 11-001
University of Massachusetts

<u>Overall Budget:</u>
Year 1 (1/1/12 - 9/30/12): $146,700
Year 2 (10/1/12 - 9/30/13): $209,944
Year 3 (10/1/13 - 9/30/14): $216,242
Year 4 (10/1/14 - 12/31/14): $65,463
Total Funding (1/1/12 - 12/31/14): $638,349

<u>Personnel:</u>
Funds are requested for 0.75 months academic salary each calendar year for the principal investigator to coordinate experimental approaches and to prepare reports and peer-reviewed articles for the project. ((b) (4) total funding including 3% COLA each year)
Rate is based on current salary and 3% COLA each year.

Funds are requested for 6 calendar months salary each calendar year for the co-principal investigator to develop novel aspects of the experimental approaches and carry out those experiments requiring substantial prior experience with nanowire experimentation including conductivity and microscopic analysis. ((b) (4) total funding including 3% COLA each year)
Rate is based on current salary and 3% COLA each year.

Funds are further requested for one part-time (6 calendar months each calendar year) postdoctoral research associate to conduct genetics studies and other aspects of the research. ((b) (4) total funding including 3% COLA each year)
Rate is based on current NIH standards and 3% COLA each year.

<u>Fringe Rates:</u>
Faculty PI ((b) (4) total funding):
- Fringe = 32.98%
- Workers Compensation = 0.38%
- Unemployment, Universal Health, MTX (Medicare tax) = 1.94%
- Health and Welfare = $14/week

Postdoctoral Co-PI and Postdoctoral Fellow ((b) (4) total funding/person):
- Workers Compensation = 0.38%
- Unemployment, Universal Health, MTX (Medicare tax) = 1.94%

Rates are based on current negotiated and approved rates.
http://www.umass.edu/research/system/files/FACTSHT2.pdf

Health Insurance:

Postdoctoral Fellow Health Insurance Plan = $278/month (September-August)
Rate is based on current negotiated cost.

http://www.umass.edu/research/system/files/FACTSHT2.pdf

Travel:

Funds are requested for travel to collaborators for experiments ($1000/person/trip), National Microbiology meetings to present data ($2000/person/trip), and Washington DC for ONR meetings ($1000/person/trip). Rate is based on previous experience with purchases for similar travel with 3% inflation rate.

Publications:

Funds are requested for publication costs ($2000/article) in peer-reviewed journals each calendar year. Rate is based on previous experience with purchases for similar publications with 3% inflation rate.

Materials and Supplies:

Funds for materials and supplies requested at an approximate rate of $25,000 per 100% effort researcher for each calendar year. Rate is based on previous experience with purchases for similar research projects with 3% inflation rate.

Materials and Supplies details:

Supply Items include: Custom glassware; electrodes; anode and cathode graphite materials; selective membranes; wires, connectors and resistors; gasket materials; gassing station components: swage fittings, flow meters, pressure gauges; reagents for analytical and electrochemical analysis; gases for anaerobic culturing and fuel cells.
Transmission electron microscopy supplies including: labeled antibodies, support film/grids and electron microscopy use, probes for thermopower and high-frequency measurements; tips for electrostatic force microscopy; liquid helium and liquid nitrogen; specific fluorophores; miscellaneous reagents for molecular, analytical, electrochemical analyses.
Molecular Biology reagents and supplies: acidic phenol, isopropanol, ethanol, isoamyl alcohol/chloroform, TE saturated phenol, linear acrylamide; Superase-In, Proteinase K, lysozyme, yeast tRNA, glycogen, Rneasy mini kits; RNA isolation aid kit; DNA-free kit; reverse transcriptase, restriction enzymes, primers, taq DNA polymerase, dNTPs; PCR primers; TOPO vector cloning kits; microarray supplies including RNA amplification kit and slide chips;
DNA sequencing supplies including Big Dye terminator kit, POP7 polymer
General laboratory reagents, supplies, and small equipment: gases for anaerobic glove bags, anaerobic culturing stations, and bench-top manipulations; columns and reagents for HPLC and ion and gas chromatographs; reagents for protein assays, disposable syringes, needles, pipette tips, filters, tubes, gloves, culturing tubes, butyl rubber stoppers, media ingredients; cell counting supplies and microscope supplies.

<u>Indirect costs:</u>
58.5% of total direct costs for 1/1/12-6/30/12
59.0% of total direct costs for 7/1/12-12/31/14

Rates are based on current negotiated and approved rates.
http://www.umass.edu/research/system/files/FACTSHT2.pdf

Further details will be supplied if requested

CLARIFICATIONS TO ONR BAA-11-001

Submittal of this proposal is based on the understanding that the University of Massachusetts will be conducting Fundamental Research and the resultant work will become part of the public domain. This type of activity is exempt from ITAR per 22 CFR 120.11 Section (a) Item (8), FAR 27.404(a) as implemented by NSDD Rule 189.

The University requests that the work be performed under the terms of a grant or cooperative agreement. If a contract is used, do not pass down Export Controlled materials. The contract will include FAR 52.227-11 Patents, FAR 52.227-14, Alt IV Data Rights and FAR 52.249-5 Termination for Convenience.

1. Section I, Section 11. Other Information, Page 13
Section II, Award Administration Information, Page 14

The University does not have a Security Clearance. The proposal offered by the University is solely intended for unclassified work.

It is the policy of the University to undertake only those research projects in which the purpose, scope, methods, and results can be fully and freely disclosed. As such, any restrictions to publishing the results of the project should be deleted.

RESEARCH & RELATED Other Project Information

1. * Are Human Subjects Involved? ☐ Yes ☒ No

1.a If YES to Human Subjects

Is the Project Exempt from Federal regulations? ☐ Yes ☐ No

If yes, check appropriate exemption number. ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

If no, is the IRB review Pending? ☐ Yes ☐ No

IRB Approval Date:

Human Subject Assurance Number:

2. * Are Vertebrate Animals Used? ☐ Yes ☒ No

2.a. If YES to Vertebrate Animals

Is the IACUC review Pending? ☐ Yes ☐ No

IACUC Approval Date:

Animal Welfare Assurance Number

3. * Is proprietary/privileged information included in the application? ☐ Yes ☒ No

4.a. * Does this project have an actual or potential impact on the environment? ☐ Yes ☒ No

4.b. If yes, please explain:

4.c. If this project has an actual or potential impact on the environment, has an exemption been authorized or an environmental assessment (EA) or environmental impact statement (EIS) been performed? ☐ Yes ☐ No

4.d. If yes, please explain:

5. * Is the research performance site designated, or eligible to be designated, as a historic place? ☐ Yes ☒ No

5.a. If yes, please explain:

6. * Does this project involve activities outside of the United States or partnerships with international collaborators? ☐ Yes ☒ No

6.a. If yes, identify countries:

6.b. Optional Explanation:

7. * Project Summary/Abstract Abstract ONR Nanowire 2011.pdf Add Attachment Delete Attachment View Attachment

8. * Project Narrative TechnicalProposal.pdf Add Attachment Delete Attachment View Attachment

9. Bibliography & References Cited References ONR Nanowire 2011.pdf Add Attachment Delete Attachment View Attachment

10. Facilities & Other Resources UMass Facilities and Equipment.pdf Add Attachment Delete Attachment View Attachment

11. Equipment Add Attachment Delete Attachment View Attachment

12. Other Attachments Add Attachments Delete Attachments View Attachments ☐

Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires

Derek Lovley and Nikhil Malvankar, Department of Microbiology, University of Massachusetts

Abstract

The surprising discovery that the proteinaceous pili of *Geobacter sulfurreducens* possess metallic-like conductivity is a paradigm shift in our understanding of electron transfer in biology and the electronic properties of biomaterials. Understanding the mechanisms underlying this metallic-like conductivity has important implications for the optimization of microbial fuel cells and other bioenergy strategies as well as for bioremediation and the development of future-generation inexpensive and environmentally sustainable nanomaterials and nanoelectronic devices. The purpose of the research proposed here is to elucidate the mechanisms for the metallic-like conductivity of *Geobacter sulfurreducens* pili. The specific short-term objectives of this research are: 1) to investigate the mechanisms underlying metallic-like conductivity; 2) to develop a structural understanding of the pili to probe the conduction mechanism at a molecular level; and 3) to identify strategies for increasing the conductance of pili. The following hypothesis will be investigated: 1) modification of the pili with attached lipids or glycosylation insulates the pili, permitting long-range electron transfer in aqueous environments; 2) pili have microscopic signatures of metallic-like conductivity; 3) reducing the disorder in pili will result in improved metallic nature; 4) the metallic-like conductivity in pili originates from the electrons delocalized along the pili filaments; 5) pili show spectroscopic signatures of electron delocalization. 6) changes in the oxidation state of pili can alter their conductivity; 7) the charge carriers in pili are p-type (holes); 8) protons act as a source of charge carriers for pili; and 9) intermolecular electron delocalization in pili originates from π-π interchain stacking among aromatic amino acids. These studies are expected to provide a basic understanding of metallic conductivity along protein filaments, which will make an important contribution to the basic understanding of biological electron transport and will significantly advance the emerging field of bioelectronics and its practical applications of interest to the Navy.

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University of Massachusetts Facilities and Equipment
Derek Lovley

Dr. Lovley's laboratory in the Department of Microbiology at the University of Massachusetts encompasses 14,336 square feet of which 11,600 square feet has been recently constructed. The laboratory is fully equipped for investigations on the physiology, ecology and molecular biology of anaerobic microorganisms.

Equipment includes: Shimadzu LCMS-2020 mass spectrometer with electrospray interface for high speed scanning and high sensitivity applications; ABI 3730XL DNA analyzer; Axon Instruments Genepix 4000B Microarray Scanner, Genpix software and Acuity database and data handler, Applied Biosystems 7500 RT-PCR, Varian Cary 50 Bio UV/Vis spectrophotometer, Shimadzu UV-2401PC UV/VIS spectrophotometer; Hewlett Packard (HP) HP6890 capillary gas chromatograph (TCD/FID/ECD detectors), Perkin Elmer Clarus 600 capillary (FID) gas chromatograph with turbomatrix headspace analyzer and autosampler; Shimadzu GC-8A/INUS gas proportional counter; HP series 1100 HPLC with diode array, fluoresence detectors and autosampler, Shimadzu SPD10 and SPD6A HPLC with UV, IR detectors and autosampler; Chemchek Instruments Kinetic Phosphorescence Analyzer KPA-11 and autosampler, Trace Analytical reduction gas analyzer for H_2 measurements; Gamry multichannel, Amel single channel potentiostats and electrochemical software; Dionex ion chromatography system ICS-1000 with degas, chromeleon SE and autosampler, and Dionex system DX 500; Nikon Eclipse E600 epifluorescent microscope with Hamamtsu Digital CCU camera, Nikon E400 phase contrast microscope with SPOT RT900 SE monochrome digital camera, QED image software and remote focus attachment mounted in anaerobic glove bag; Leica TCS SP5 Spectral Confocal Upright Microscope with scanning stage, fluorescence/reflection detectors, Amersham Pharmacia fast protein liquid chromatography system; Amersham Multiphor II 2-D electrophoresis system; multiple spectrophotometers suitable for scans and kinetic studies; BioRad flourometer; multiple low speed, ultra and micro centrifuges; electrophoresis equipment for agarose gels and polyacrylamide gels; liquid scintillation counter, 5-Coy anaerobic chambers, anaerobic gassing apparatus, incubators, Baker laminar flow sterile UV hoods, multiple Perkin Elmer and MJ Research thermocyclers, hybridization ovens, UV cross linkers, UV light boxes, electroporation apparatus, multiple blotting apparatus, french press, sonicator, speed vacuum system, photographic equipment, walk in incubators for sediment and cultures, -80 °C freezers, Milli Q and Nanopure deionized water filtration units, Anprolene ethylene oxide sterilizer with scrubber, water baths, pipettors refrigerators etc. Laboratories are equipped with fume hoods, and gas, steam and distilled water lines. Additional autoclaves, walk-in incubators, low speed refrigerated centrifuges, ultracentrifuges and rotors are available in the Department of Microbiology.

Computer equipment : Sun Fire V880 server, CDC 2460 Simpheny-DB 2460 Dual Intel PIV Xeon Server; NIXSYS NIX2000-8RD Tyan Thunder 2xAMD Opteron dual core with RAID, Mac or PC workstations for each postdoc, graduate student and for analytical equipment.

The following facilities are available for analysis: Electron Microscopy Facilities in the departments of Microbiology, Polymer Science and Physics at Umass Amherst, MALDI-TOF/MS analyses at the University of Mass, Worcester.

University of Massachusetts Facilities and Equipment Safety

At the University of Massachusetts, Amherst, a university wide safety plan is in effect through the Environmental Health and Safety Program. This plan is based on applicable health and safety standards promulgated by Federal and State agencies including OSHA Occupational Exposure to Hazardous Chemicals in Laboratories and published standards of nationally recognized professional health and safety groups. In accordance with federal mandates the following committees are established at the University of Massachusetts: the Radioisotope Use Committee, the Recombinant DNA Committee (Guidelines for Research involving recombinant DNA molecules by the NIH followed), Biological Hazards Committee, Institutional Animal Care and Use Committee and Chemical Hazards Committee. These committees have established safety and health policies in accordance with federal, state, and local laws and regulations. Our laboratory is regularly inspected for compliance to health and safety as well as waste minimization and waste disposal requirements.

Technical Proposal
Cover Page

ONR BAA Announcement #11-001

Title: Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires

Prime Offeror: University of Massachusetts, Amherst
Principal Investigator: Derek R. Lovley

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Proposed period of performance: Three calendar years

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Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires

Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires

Derek Lovley and Nikhil Malvankar, Department of Microbiology, University of Massachusetts

Abstract

The surprising discovery that the proteinaceous pili of *Geobacter sulfurreducens* possess metallic-like conductivity is a paradigm shift in our understanding of electron transfer in biology and the electronic properties of biomaterials. Understanding the mechanisms underlying this metallic-like conductivity has important implications for the optimization of microbial fuel cells and other bioenergy strategies as well as for bioremediation and the development of future-generation inexpensive and environmentally sustainable nanomaterials and nanoelectronic devices. The purpose of the research proposed here is to elucidate the mechanisms for the metallic-like conductivity of *Geobacter sulfurreducens* pili. The specific short-term objectives of this research are: 1) to investigate the mechanisms underlying metallic-like conductivity; 2) to develop a structural understanding of the pili to probe the conduction mechanism at a molecular level; and 3) to identify strategies for increasing the conductance of pili. The following hypothesis will be investigated: 1) modification of the pili with attached lipids or glycosylation insulates the pili, permitting long-range electron transfer in aqueous environments; 2) pili have microscopic signatures of metallic-like conductivity; 3) reducing the disorder in pili will result in improved metallic nature; 4) the metallic-like conductivity in pili originates from the electrons delocalized along the pili filaments; 5) pili show spectroscopic signatures of electron delocalization. 6) changes in the oxidation state of pili can alter their conductivity; 7) the charge carriers in pili are p-type (holes); 8) protons act as a source of charge carriers for pili; and 9) intermolecular electron delocalization in pili originates from π-π interchain stacking among aromatic amino acids. These studies are expected to provide a basic understanding of metallic conductivity along protein filaments, which will make an important contribution to the basic understanding of biological electron transport and will significantly advance the emerging field of bioelectronics and its practical applications of interest to the Navy.

Introduction

Microbial nanowires were initially of interest because their function is key to the optimization of microbial fuel cells. The discovery of metallic-like conductivity in microbial nanowires has broadened their potential application to the development of a novel class of electronic materials that can be generated inexpensively and sustainably with desirable characteristics such as the ability to function under water and to electronically interface biological and abiological materials. Organic-based electronics could have a broad range of applications such as multifunctional electronics for intelligent naval sensors, decision support systems, and nanoelectronics. Optimization of these applications requires an understanding of how electrons flow thorough microbial nanowires and the identification of factors limiting their conductivity.

The purpose of the research outlined in this proposal is to provide mechanistic insights into the mechanism of conductivity in microbial nanowires, as well as to provide structural and molecular basis underlying the conductivity. These studies are expected to lead to an improved understanding of the components of microbial nanowires contributing to the conductivity and to elucidate the factors limiting the conductivity.

Our recent ONR-supported research has revealed that microbial nanowires exhibit metallic-like conductivity, a property that has not previously been observed in any natural proteins (1). Furthermore, the nanowire networks were conductive over centimeter-long distances, thousands of times the size of a microbial cell. This surprising finding challenges a central dogma of biology that electron transfer in living systems can happen only by electron tunneling or hopping, over short distances. The conductivity of microbial nanowires can be altered with temperature and pH, similar to synthetic organic metals. Additionally, the conductivity of biofilms, comprised of microbial nanowire networks, is “tunable” by changing patterns of gene expression as well as by gate voltage in a transistor configuration.

One feature of microbial nanowires which is significantly different than abiological electronic materials is their ability to conduct electrons in an aqueous environment. Semiconductor-based electronics are not durable in aqueous environments due to corrosion and degradation. Current semiconductor technology also faces corrosion issues in acidic media whereas the conductivity of microbial nanowires actually increases with decreasing pH. The microbial nanowires were 10-fold more conductive at pH 2 than at neutral pH 1 (1). The ability of microbial nanowires to effectively conduct current through water suggests that the nanowires may be shielded with an insulating layer. Consistent with this hypothesis, is the finding from our previous atomic force microscopy studies that it was necessary to scrape as-yet-undefined material from the nanowire surface in order to measure conductivity across the diameters of the nanowires (2). Elucidation of the potential insulating material is one of the main focuses of the proposed research.

Studies of other type IV pili have suggested several ways in which these pili may be modified, which *Geobacter* species might use as a strategy for insulating microbial nanowires.

For example, the type IV pili of *Neisseria*, *Pseudomonas*, *Dichelobacter*, *Francisella* and *Deinococcus* may have a number of post-translational modifications (3-6). Pilin subunits in *Neisseria* species can be modified with the addition of phosphoethanolamine, phosphocholine, or phosphoglycerol to serine residues present within the C terminus of the monomer (3,7,8). The glycerylphosphate modification has been suggested to serve as a substrate for lipid attachment (7). Coating the pili with lipid could be a strategy for insulation. Another option is glycosylation. Pili can be glycosylated through O-linkages with di and tri-saccharides at serine residues on the pili. In *P. aeruginosa* strain 1244, the pilin saccharide attachment is catalyzed by an oligosaccharyl transferase coded by the gene *pilO* (9). Disrupting *pilO* is a strategy for investigating the potential for glycosylation. As outlined in the approach section, the possibility of nanowire insulation with either glycosylation or lipid attachment will be investigated.

The initial impetus for studying the properties of microbial nanowires was their essential role in producing high current densities with microbial fuel cells (10,11). Our recent ONR-supported research demonstrated that extracellular electron transfer via biofilms, with conductivity associated with microbial nanowires, provides the most efficient mechanism for conversion of wastes into electricity and the conductivity is a necessary requirement for achieving high current density in microbial fuel cells (12).

Another bioelectronic application of interest to the Navy may be energy storage. Our ONR-supported research has further demonstrated that it is possible to generate biological supercapacitors, based on c-type cyotochromes (13). The specific capacitance of the supercapacitor device is comparable to the devices derived from synthetic materials (13).

Metallic-like conductivity along native protein filaments represents a paradigm shift in our understanding of electron transfer in biology and electronic properties of biomaterials. It provides a strong foundation for a new field of biologically-produced electronic materials. The demonstrated ability to engineer metallic functionality into natural, self-renewing, nanostructured materials introduces new materials and concepts and may offer possibilities for overcoming barriers associated with coupling abiotic and biotic materials in nanobioelectronics (14) and could provide insights for engineering similar functionalities into synthetic materials (15).

Progress under Previous ONR-Funded Research

The Importance of Pili in Extracellular Electron Transfer

Our previous ONR-supported research suggested that pili act as conduit for electron transfer between the cells of *Geobacter sulfurreducens* and the anode of microbial fuel cells (10). Thick biofilms (ca. 80 µm) grew on the anode. Thus, most of the cells were not in direct contact with the electrode. In spite of this lack of direct contact, the current increased linearly with the biofilm thickness suggesting that there must be a mechanism for cells at great distance from the anode to directly transfer electrons to the anode. Deletion of the gene for PilA, the structural pilin protein, inhibited the formation of thick biofilms and produced current comparable to that previously observed with cells in direct contact with the electrode. These studies suggested that the microorganism employ pili for long-distance electron transport by forming a conductive network. This observation led to the hypothesis that *Geobacter* biofilms are electronically conductive. Subsequent modeling studies suggested that the large biofilm conductivity can explain the high-current density of *Geobacter*-based microbial fuel cells (16). Further studies evaluated gene expression in the thick biofilms using whole-genome DNA microarrays (11). The most highly upregulated genes in the thick anode biofilm cells were genes associated with the formation of pili, consistent with the requirement of pili for thick biofilms.

Although the studies described above suggested that pili were important for long-range electron transport through the anode biofilms, the concept that protein filaments could be conductive along their length was received with considerable skepticism because there was no known mechanism for electron transfer along protein filaments (17). It was long believed that the electron transfer in living systems could only proceed either by electron tunneling or hopping using redox-active metalloproteins and the possibility of long-distance electron transport in proteins via metallic-like conductivity has been refuted by the authoritative reviews (18-20). Furthermore, the hypothesis that the *G. sulfurreducens*' biofilms were conductive was in conflict with previous studies that demonstrated that the biofilms of commonly studied microorganisms act as insulators and not conductors (21-23).

Several reports suggested that electron transfer along pili must be via electron hopping through cytochromes aligned along the pili filaments (24-28). Later studies did demonstrate that the *c*-type cytochrome, OmcS, aligns along the pili filaments of *G. sulfurreducens* (29), but the spacing between the cytochromes was too great for cytochrome-to-cytochrome electron transfer to account for long-range electron conduction along the pili. Therefore, the available evidence was consistent with long-range electron transport along the pili, but this had not been directly measured and there was no precedent for a mechanism.

Direct Measurements of Biofilm and Pili Conductivity

In order to directly measure the proposed conductivity *in situ*, the biofilms of *G. sulfurreducens* were grown using a novel split-anode microbial fuel cell comprised of two gold anodes separated by a 50 µm non-conductive gap (1). As biofilms grew over the electrodes, they bridged the gap and became confluent. Connecting the two anodes to electronics allowed the measurement of biofilm conductivity using DC current/voltage characteristics. Biofilms showed very high electronic conductivity, comparable to the films comprised of synthetic organic metallic nanostructures such as polyaniline and polyacetylene. AC impedance spectroscopy measurements further confirmed the electronic conductivity of biofilms.

In order to elucidate the components contributing to biofilm conductivity, biofilms of several strains and mutants of *G. sulfurreducens* that differed in their capacity to produce pili were evaluated in the split-anode system. These studies revealed a strong correlation between biofilm conductivity and pili protein abundance, suggesting that pili were contributing to biofilm conductivity (1).

In order to directly evaluate pili conductivity, filament preparations of *G. sulfurreducens* were placed on the split-gold electrodes and dried in a desiccator. On electrodes, the sheared pili filaments formed a network similar to that present in biofilms. The pili filaments of wild-type cells had conductivity similar to the anode biofilms under similar experimental conditions. In contrast when filament preparations were made from a strain in which the gene for PilA had been deleted the conductivity was comparable to that of the buffer control. These studies demonstrated that the filament conductivity is associated with the PilA protein and that pili can form a network with sufficient conductivity to account for electron flow in biofilms (1).

Metallic-like Conduction Mechanism in Biofilms and Pili

Insights into the conduction mechanism for biofilms and pili were obtained by measuring conductivity as a function of temperature and electrochemical gating. Upon cooling from room temperature, the conductivity increased exponentially – a hallmark of quasi-one-dimensional organic metals. Electrochemical gating showed a sigmoidal response, which is a characteristic of organic metals. Both of these results indicated that pili conduct electrons in a manner similar to synthetic organic metals. The pili filament conductivity increased by two orders of magnitude with pH changes suggesting that pili can be doped with protons which can act as a source of carriers. Both the electrochemical gating and pH experiments indicated that the charge carriers in the pili are p-type. Structural studies using X-ray diffraction analysis of purified pilin preparations revealed π-π interchain stacking between aromatic moieties of pilin amino acids that may confer the metallic-like conductivity (1).

Lack of Involvements of *c*-type Cytochromes in Biofilm and Pili Conductivity

Treating pilin preparations to denature any cytochromes that might have remained associated with the pili had no impact on conductivity (1), suggesting that pili conductivity cannot be attributed to *c*-type cytochromes. Furthermore, there was no correlation between the conductivity of biofilms of different strains of *G. sulfurreducens* that differed in their ability to produce cytochromes and cytochrome abundance in the biofilms (1). Furthermore, denaturing the cytochromes within biofilms did not affect the conductivity of biofilms, indicating that cytochromes did not confer conductivity to biofilms. The temperature and the electrochemical gating response would not have been observed if electron hopping between cytochromes was responsible for the electron transfer. The biofilm conductivity estimated using the reported diffusion coefficients and the measured concentration of cytochoromes was only 0.05% of the measured conductivity.

These multiple lines of evidence demonstrated that *c*-type cytochromes are not involved in long-distance electron transport along pili (1). The more likely role of outer surface *c*-type cytochromes is to facilitate short-range electron transfer from pili to iron oxide or from biofilm to anodes of microbial fuel cell (1).   They may also play a role in the pilin-mediated electron transfer between cells, a recently recognized novel strategy for syntrophic interaction between anaerobic microorganisms (30,31)

Supercapacitor Behavior of Biofilms

Another remarkable feature of *G. sulfurreducens*' biofilms is their ability to function as a supercapacitor (13). Electrochemical impedance spectroscopy demonstrated that *G. sulfurreducens*' biofilms exhibited significant capacitance. The capacitance was proportional to the abundance of cytochromes in biofilms of different *G. sulfurreducens* strains and denaturing the cytochromes eliminated the biofilm capacitance. Furthermore, the capacitance of the biofilms compared very well with the expected capacitance that was calculated from the abundance of cytochromes in the biofilms. Only conductive biofilms had high capacitance, suggesting that pili play an important role in transferring electrons to the cytochromes for temporary storage. The specific capacitance of the *G. sulfurreducens*' biofilms was comparable to synthetic supercapacitors, offering prospects for future energy storage devices.

Implications

The demonstration of metallic-like electron transport along a native protein filament without the involvement of cytochromes is a paradigm shift in biology. It is important to note that the metallic-like mechanism for electron transport along the pili of *G. sulfurreducens* under *in vivo* conditions is fundamentally different than the conductivity proposed for filaments of other microorganisms such as *Shewanella oneidensis*, which was only demonstrated in fixed preparations and was reported to be dependent on the presence of cytochromes (32,33). A deeper understanding of electron transport mechanism in the pili of *G. sulfurreducens* will aid in realizing their potential applications in bioenergy and bioremediation, as well as in protein-based nanotechnology (34).

OBJECTIVES AND HYPOTHESES

Objectives

The overall objective of these studies is to elucidate the mechanisms for the metallic-like conductivity of *Geobacter sulfurreducens* pili. The specific short-term objectives of this research are: 1) to investigate the mechanisms underlying metallic-like conductivity; 2) to develop a structural understanding of the pili to probe the conduction mechanism at a molecular level; and 3) to identify strategies for increasing the conductance of pili.

Hypotheses

1. (b) (4)
2. Pili have microscopic signatures of metallic-like conductivityPili show microscopic signatures of metallic-like conductivity.
3. (b) (4)
4. The metallic-like conductivity in pili originates from the electrons delocalized along the pili filaments.
5. Pili show spectroscopic signatures of electron delocalization.
6. (b) (4)
7. The charge carriers in pili are p-type (holes).
8. Protons act as a source of charge carriers for pili.
9. Intermolecular electron delocalization in pili originates from π-π interchain stacking among aromatic amino acids.

Approach

A description of the experimental approach to the individual hypotheses is described below.

Hypothesis 1. (b) (4)

(b) (4)

Hypothesis 2. Pili show microscopic signatures of metallic-like conductivity.

The temperature dependence of pili conductivity indicated metallic-like behavior and suggested that pili are akin to quasi-one-dimentional (Q1D) disordered metals (1) . The electron transport in pili exhibits a crossover from intrinsic metallic-like transport to thermally activated hopping transport expected for disordered metals at a crossover temperature $T_\xi \approx$ 270-280 K (1). Similar temperature-driven crossovers have been observed previously in a number of disordered Q1D inorganic (35) and organic (36,37) metallic conductors . Despite disorder, these materials show metallic, large conductivitiy at room temperature due to strong inelastic scattering. The electron scatters to another state and becomes localized around a different site before diffusing over the localization length. This regime is referred to as the weak localization (WL) regime. It is well documented that the electronic properties of disordered organic metals result from weak localization (38,39). With decreasing temperature, a low-dimentional conductor eventually becomes an insulator and electron transport can proceed only by hopping. This regime is referred to as strong localization (SL) regime. The study of temperature-driven crossover is more informative over gate voltage induced crossover since the WL and SL regimes are pertinent to the same electron states

This property will be further probed at the microscopic level with magnetic field dependence of conductivity. Magnetoconductance (MC) is an important physical quantity to study the microscopic nature of electron transport. The conductivity measurements probe macroscopic scale properties while MC is mainly influenced by the local microscopic scale transport parameters (40). Quantum interference of more than one current paths leads to a decrease in conductance in disordered metals. However, in the presence of a magnetic field, phase factors of electron wavefunctions change. This change in electron phase causes the destruction of quantum interference and the increase in the conductance (41). For metallic systems, positive MC is expected due to the destruction of quantum interference of delocalized electron wavefunctions by an applied magnetic field whereas for semiconducting/insulating systems, negative MC is expected due to the shrinkage of localized electron wavefunctions by an applied magnetic field (40). In order to probe the local, microscopic electron trassport, pili conductance will be measured as a function of magnetic field.

Our preliminary studies using magnetic field are consistent with the metallic-like nature of pili conductivity (42). Upon application of a magnetic field, MC of pili increased 10,000 % in a manner similar to that previously reported for organic metals. Pili showed a field-induced and temperature-dependent crossover from the positive to negative MC. This crossover is a characteristic of metal-insulator transition. Thus, the magnetic field dependence of pili conductivity is consistent with the temperature dependence of conductivity.

However, the application of magnetic field on pili caused a structural rearrangement of the pilin network. The interpenetrating network of pili was transformed into parallel, aligned filaments. The increase in MC due to the alignment further demonstrates the quasi-one-dimensional nature of pili conductivity. But this structural rearrangement caused hysteresis in MC and made it difficult to interpret the data solely on the basis of quantum interference effects. Therefore, further studies will be performed on pre-aligned pili to distinguish the contribution of structural rearrangement from the quantum interference effects. Typical physical parameters such as the localization length and the coherence length will be computed from MC data and will be compared to the magnetic length. It is expected that when the localization length becomes comparable to the magnetic length, pili will show a positive MC. Preliminary results are consistent with this behavior.

Hypothesis 3. (b) (4)

Hypothesis 4. The metallic-like conductivity in pili originates from the electrons delocalized along the pili filaments.

The temperature (1) and magnetic-field (42) dependence of pili conductivity indicated that the conduction mechanism in pili is metallic-like and that pili undergo disorder-induced metal-insulator transition. Magnetic susceptibility studies will be performed to further understand the nature of metal-insulator transition in pili (43). Metallic conduction behavior is thought to arise from spin delocalization, which can be identified with magnetic measurements. The diamagnetic behavior is associated with the metallic response meaning that a spin delocalization occurs and a typical metallic diamagnetism can be observed. At lower temperatures the spins are freezing, the system suffers from the Peierls instability, and the electrons become localized, giving rise to a metal-insulator transition and an associated paramagnetism (43). Thus, the metal-insulator transition can be studied in detail with magnetic measurements. Our initial studies on magnetic properties of pili are consistent with this mechanism. Pili showed a crossover from a diamagnetic response to a paramagnetic behavior with a decrease in temperature suggesting a metal-insulator transition due to spin localization. Further detailed experiments and analysis will fully elucidate the mechanism of metallic conductivity in pili.

Previous measurements on pili conductivity were performed at very low frequency (in the DC limit). Pili conductivity will be measured at high frequency to further probe the metallic nature of conductivity. It is known that the conductivity of metallic samples hardly shows any frequency dependence at any temperatures, whereas semiconducting and insulating systems have pronounced frequency dependence of conductivity, especially at low temperatures, because the hopping transport is modified at higher frequencies (40). Understanding the origin of the metal-insulator transition will help to improve the intrinsic metallic nature of pili, which will enhance the resultant conductivity.

The electron delocalization in pili will be further evaluated with electron spin resonance (ESR). ESR is a special case of electron paramagnetic resonance, in which only the spin of the electron matters (44). In a magnetic field, energy levels of atoms are separated proportional to the strength of the magnetic field. When a sample is placed in a waveguide and the transmission of the electromagnetic waves through the sample is measured as a function of frequency, absorption of energy can be observed at a characteristic energy equal to the separation of the energy level due to magnetic field. This phenomenon is known as resonant absorption. If pili contain delocalized electrons, these free electrons may possess a net spin that will contribute to the energy level separation due to applied magnetic field. The resonant absorption of electromagnetic waves will demonstrate the presence of delocalized electrons and the magnitude of the response can serve as the measure of their concentration. Moreover, ESR can be used to locate the position of unpaired electron spin in pili (44).

Intermolecular electron delocalization in pili will be further confirmed using electrostatic force microscopy (EFM). EFM is very sensitive to local charge distribution and can be employed on individual filaments (45). Charge injection experiments will be carried out by touching the conductive tip to the pili surface, applying a bias to the tip, and detecting the injected charge with EFM. Similar approaches have been previously employed to observe electron delocalization in carbon nanotubes (45). The dark image of the uncharged filament transforms into the bright image resulting from the delocalization of the injected charge. Additionally, this technique will be employed to locate the charge storage sites on pili (45).

Hypothesis 5. Pili show spectroscopic signatures of electron delocalization.

Previous experiments on *G. sulfurreducens* biofilms using Fourier-transformed Infrared (FTIR) spectroscopy suggested the presence infrared-active vibration modes and ultraviolet-visible-near infrared (UV-vis-NIR) spectroscopy showed a strong absorbance in NIR region, indicating the presence of aromatic structures causing electron delocalization and conferring metallic-like conductivity to these materials. These initial spectroscopic studies are consistent with our recent findings using X-ray diffraction that suggest that pili exhibit interchain π-π stacking among aromatic residues (1). Both FTIR and UV-vis-NIR spectroscopy will be performed on pili as a function of pH and gate voltage to further probe the different structural components contributing to pili conductivity (46).

Magnetic field studies indicated that the quantum interference process regulates the electron flow in pili (42). Several experimental parameters, such as the electron coherence length and the localization length, were comparable to that previously observed in organic metals (42). However, more direct techniques are necessary in order to directly probe the electron coherence in pili. Recently, two-dimensional photon-echo spectroscopy has been used to study the quantum nature of the energy transfer in photosynthetic proteins of the green sulfur bacterium *Chlorobium tepidum* (47). In collaboration with the Graham Fleming group at Berkeley, similar studies will be performed on pili to characterize the electron coherence time. These studies will provide unprecedented insights into the microscopic nature of conduction in pili.

Hypothesis 6. (b) (4)

(b) (4)

Hypothesis 7. The charge carriers in pili are p-type (holes).

The identification of the sign and the nature of charge carriers are very important for future application of pili-based electronics and to understand their function in microbial respiration. Our previous ONR-supported studies on biofilms using electrolyte-gated field-effect transistor revealed that charge carriers are p-type and the conductivity can be regulated by a gate voltage in a transistor configuration (1). These results are consistent with protonation studies which have also suggested that the charge carriers in pili are p-type (1).

To further explore the sign and the nature of charge carriers in pili, electrochemical gating studies will be performed directly on pili. This technique has been used previously to probe the electronic structure of carbon nanotubes (50) and it is expected that the transistor studies on pili will help in resolving their electronic structure. Furthermore, back-gating or top-gating will be employed on pili using suspended electrodes to suppress the electrode effects. Initial studies on biofilms with back-gating have shown a transistor-like behavior. Furthermore, gating studies will be performed at various pH values to further understand the role of protonation in conductivity.

Additionally, thermopower measurements will be used to study the sign of charge carriers (37). The thermopower, which is a measure of the rate of diffusion of charge carriers in response to a thermal gradient, is a transport property that is usually less affected by materials imperfections than the conductivity, and therefore can help identify the intrinsic conduction processes. As the doping level increases, the thermopower decreases, until for the fully doped samples the thermopower shows remarkably good agreement with proportionality to the temperature expected for metallic diffusion thermopower. The positive sign in the temperature-dependence of thermopower is expected for hole-like carriers while negative sign indicates electron-like carriers (37). Therefore, the thermopower measurements on pili at various pH are expected to provide the information about the nature of charge carriers and the intrinsic conduction process with less effect of the intrinsic disorder.

Hypothesis 8. Protons act as a source of charge carriers for pili.

The understanding of the source of charge carriers for the observed metallic-like conductivity is crucial for development of future-generation protein-based electronically functional biomaterials. Our previous ONR-supported research showed that the conductivity of pili is pH-dependent (1). Decreasing pH increased the conductivity by over two orders of magnitude. Both electrochemical gating and protonation experiments suggested that the charge carriers in pili are p-type (1).

These results suggest that both imine and amine nitrogens in pili can bind to protons which can act as a source of conductivity. The conductivity of pili mainly increased in the pH range 8-10, suggesting that the amino acids with high pKa, such as tyrosine and lysine, which can be protonated at this pH, are participating in electron transport. Both of these amino acids are present in C-terminal portion of the pilin protein which is exposed to the external environment. Other candidates which contain imine nitrogens are arginine, which is also present in the exterior of the pili, or histidine which is present in the signal peptide for pilin but not in pilin itself. Using a site-directed mutagenesis approach, we will evaluate the role of key amino acids in pili.

However, it is possible that pH effect might induce some structural rearrangements in pili (51). This possibility will be evaluated using electron microscopy and spectroscopic tools. Specifically, the pH-dependence of pili can be further studies by comparing conductivity data with respective circular dichroism (CD) spectra at a particular pH (52,53). CD at basic pH typically led to little or no absorbance in the low-energy visible region, but acidic solutions show very strong and characteristic bisignate cotton effects indicative of chromophore interactions within helical or otherwise chiral environments. These experiments can also reveal the degree of electron delocalization in pili filaments.

Hypothesis 9. Intermolecular electron delocalization in pili originates from π-π interchain stacking among aromatic amino acids.

In organic metals, conductivity arises due to the overlap of π orbitals, which can be due to aromatic ring stacking (39,43). Structural studies on pili with X-ray powder diffraction revealed that pili have a tightly packed crystalline structure. Notably, the sharp peak corresponding to 3.5 Å that was observed for pili has been previously reported in many conductive materials based on aromatic ring stacking (39,43,54). These studies suggested that phenyl rings in phenylaniline or phenol rings in tyrosine which are present in the exterior of pili might be π-stacked, allowing efficient intermolecular delocalization and conferring metallic-like conductivity to pili.

The X-ray fiber diffraction method will be used to complement the X-ray powder diffraction studies. This method has been used previously to provide useful filament models (55). This study will be particularly useful to gain information about intermolecular spacing between various structural features of pili such α-helix and β-sheets.

Spectroscopic studies on biofilm and pili were previously performed using UV-visible-near infrared and Fourier transform infrared spectroscopy. These studies indicated that aromatic structures in biofilm and pili can absorb in near-infrared region suggesting electron delocalization. Thus initial spectroscopic studies are also consistent with metallic-like conduction mechanism (54). However, due to low signal levels associated with small quantities of pili in the preparations, the initial results on pili are ambiguous. Both X-ray diffraction and spectroscopy studies will now be performed on pili filaments of wild-type as well as the mutant strains in which specific amino acids are altered.

Further structural studies on pili will be performed using a combination of techniques. For example, cryo-electron microscopy will be employed to gain structural insights. This technique has been used previously to resolve the structure of type IV pili with 2.3 Å resolution (56). We will also use high-resolution transmission electron microscopy (HRTEM) to develop a three-dimensional reconstruction of the pili, following previously described methods (57). Information about the size of α-helix backbone and the organization of subunits in pili can be obtained with this technique.

Nuclear magnetic resonance (NMR) will be used to probe the pili structure and to evaluate the role of aromatic amino acids in interchain π-π stacking observed via X-ray diffraction studies. This method has been recently used to probe π-π interaction in other proteins (58,59). NMR will be used to probe any structural changes that take place during protonation as a function of pH. The information about the variations in the proton resonances of key amino acids will be used to evaluate their role in conductivity.

Circular dichroism (CD) spectroscopy will be used to gain information about the secondary structure of pili (52,53). Most importantly, CD spectra can reveal electron delocalization present in protein structures.

In order to understand the role of different amino acids in pili conductivity, tertiary structure of pilin protein will be studied using protein structure programs such as Gromacs, Robetta or I-Tasser. These protein structure prediction programs are capable of reconstructing tertiary structure from primary amino acid sequence and will suggest the possible locations of several key amino acids, such as tyrosine, in pilin structure. Initial structural studies on pili using I-Tasser have indicated the location of several aromatic amino acids that might be important for conductivity. Possible changes in the structure and the assembly due to the replacement of key amino acids using a site-directed mutagenesis approach will be monitored using these programs.

All of the above studies will complement the current efforts to evaluate the role of amino acids with a site-directed mutagenesis approach in which we are systematically swamping out amino acids in the pilin protein and assessing the impact on pilin conductivity. These studies are expected to provide crucial insights into the origin of metallic conductivity in pili proteins.

Benefits and Significance

These studies are expected to provide significant new insights into the mechanism of metallic-like conductivity in *Geobacter* pili. The results should clearly demonstrate the microscopic origin behind the metallic-like nature of pili conductivity. This improved understanding of electron transport in pili will aid in the design and optimization of bioenergy and bioremediation strategies.

Furthermore, metallic-like conductivity in proteins has important implications for the development of future organic-based nanoelectronic devices such as transistors and capacitors. These studies will provide structural and molecular basis of electron delocalization in biological protein filaments, providing a strong foundation for the new field of biological metals. Thus, the fundamental studies on microbial nanowires described here are expected to lead to the further-generation, protein-based nanotechnology and bionanoelectronics.

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25. Strycharz, S.M., Malanoski, A.P., Snider, R.M., Yi, H., Lovley, D.R., & Tender, L.M., Application of cyclic voltammetry to investigate enhanced catalytic current generation by biofilm-modified anodes of Geobacter sulfurreducens strain DL1 vs. variant strain KN400. *Energy & Environmental Science* 4 (3), 896-913 (2011).
26. Fricke, K., Harnisch, F., & Schröder, U., On the use of cyclic voltammetry for the study of anodic electron transfer in microbial fuel cells. *Energy & Environmental Science* 1 (1), 144-147 (2008).

27. Strycharz-Glaven, S.M., Snider, R.M., Guiseppi-Elie, A., & Tender, L.M., On the electrical conductivity of microbial nanowires and biofilms. *Energy & Environmental Science* Advance Article (2011).
28. Rollefson, J.B., Stephen, C.S., Tien, M., & Bond, D.R., Identification of an Extracellular Polysaccharide Network Essential for Cytochrome Anchoring and Biofilm Formation in Geobacter sulfurreducens. *J. Bacteriol.* 193 (5), 1023-1033 (2011).
29. Leang, C., Qian, X., Mester, T., & Lovley, D.R., Alignment of the *c*-type cytochrome OmcS along pili of *Geobacter sulfurreducens*. *Appl. Environ. Microbiol.* 76 (12), 4080-4084 (2010).
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40. Bhatia, R., Sangeeth, C.S.S., Prasad, V., & Menon, R., Unusual metallic-like transport near the percolation threshold. *Applied Physics Letters* 96 (24), 242113 (2010).

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42. Malvankar, N., Vargas, M., Lovley, D., & Tuominen, M., Experimental observation of very large magnetoconductance in microbial nanowires. *American Physical Society (APS) March Meeting*, abstract #X30.00005 (2011).
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46. Yuen, J., Dhoot, A., Namdas, E., Coates, N., Heeney, M., McCulloch, I., Moses, D., & Heeger, A., Electrochemical doping in electrolyte-gated polymer transistors. *J. Am. Chem. Soc* 129 (46), 14367-14371 (2007).
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56. Craig, L., Volkmann, N., Arvai, A., Pique, M., Yeager, M., Egelman, E., & Tainer, J., Type IV pilus structure by cryo-electron microscopy and crystallography: implications for pilus assembly and functions. *Molecular cell* 23 (5), 651-662 (2006).
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University of Massachusetts Facilities and Equipment
Derek Lovley

Dr. Lovley's laboratory in the Department of Microbiology at the University of Massachusetts encompasses 14,336 square feet of which 11,600 square feet has been recently constructed. The laboratory is fully equipped for investigations on the physiology, ecology and molecular biology of anaerobic microorganisms.

Equipment includes: Shimadzu LCMS-2020 mass spectrometer with electrospray interface for high speed scanning and high sensitivity applications; ABI 3730XL DNA analyzer; Axon Instruments Genepix 4000B Microarray Scanner, Genpix software and Acuity database and data handler, Applied Biosystems 7500 RT-PCR, Varian Cary 50 Bio UV/Vis spectrophotometer, Shimadzu UV-2401PC UV/VIS spectrophotometer; Hewlett Packard (HP) HP6890 capillary gas chromatograph (TCD/FID/ECD detectors), Perkin Elmer Clarus 600 capillary (FID) gas chromatograph with turbomatrix headspace analyzer and autosampler; Shimadzu GC-8A/INUS gas proportional counter; HP series 1100 HPLC with diode array, fluoresence detectors and autosampler, Shimadzu SPD10 and SPD6A HPLC with UV, IR detectors and autosampler; Chemchek Instruments Kinetic Phosphorescence Analyzer KPA-11 and autosampler, Trace Analytical reduction gas analyzer for H_2 measurements; Gamry multichannel, Amel single channel potentiostats and electrochemical software; Dionex ion chromatography system ICS-1000 with degas, chromeleon SE and autosampler, and Dionex system DX 500; Nikon Eclipse E600 epifluorescent microscope with Hamamtsu Digital CCU camera, Nikon E400 phase contrast microscope with SPOT RT900 SE monochrome digital camera, QED image software and remote focus attachment mounted in anaerobic glove bag; Leica TCS SP5 Spectral Confocal Upright Microscope with scanning stage, fluorescence/reflection detectors, Amersham Pharmacia fast protein liquid chromatography system; Amersham Multiphor II 2-D electrophoresis system; multiple spectrophotometers suitable for scans and kinetic studies; BioRad flourometer; multiple low speed, ultra and micro centrifuges; electrophoresis equipment for agarose gels and polyacrylamide gels; liquid scintillation counter, 5-Coy anaerobic chambers, anaerobic gassing apparatus, incubators, Baker laminar flow sterile UV hoods, multiple Perkin Elmer and MJ Research thermocyclers, hybridization ovens, UV cross linkers, UV light boxes, electroporation apparatus, multiple blotting apparatus, french press, sonicator, speed vacuum system, photographic equipment, walk in incubators for sediment and cultures, -80 °C freezers, Milli Q and Nanopure deionized water filtration units, Anprolene ethylene oxide sterilizer with scrubber, water baths, pipettors refrigerators etc. Laboratories are equipped with fume hoods, and gas, steam and distilled water lines. Additional autoclaves, walk-in incubators, low speed refrigerated centrifuges, ultracentrifuges and rotors are available in the Department of Microbiology.

Computer equipment : Sun Fire V880 server, CDC 2460 Simpheny-DB 2460 Dual Intel PIV Xeon Server; NIXSYS NIX2000-8RD Tyan Thunder 2xAMD Opteron dual core with RAID, Mac or PC workstations for each postdoc, graduate student and for analytical equipment.

The following facilities are available for analysis: Electron Microscopy Facilities in the departments of Microbiology, Polymer Science and Physics at Umass Amherst, MALDI-TOF/MS analyses at the University of Mass, Worcester.

University of Massachusetts Facilities and Equipment Safety

At the University of Massachusetts, Amherst, a university wide safety plan is in effect through the Environmental Health and Safety Program. This plan is based on applicable health and safety standards promulgated by Federal and State agencies including OSHA Occupational Exposure to Hazardous Chemicals in Laboratories and published standards of nationally recognized professional health and safety groups. In accordance with federal mandates the following committees are established at the University of Massachusetts: the Radioisotope Use Committee, the Recombinant DNA Committee (Guidelines for Research involving recombinant DNA molecules by the NIH followed), Biological Hazards Committee, Institutional Animal Care and Use Committee and Chemical Hazards Committee. These committees have established safety and health policies in accordance with federal, state, and local laws and regulations. Our laboratory is regularly inspected for compliance to health and safety as well as waste minimization and waste disposal requirements.

Biographical Sketch-Derek R. Lovley

Department of Microbiology, University of Massachusetts, Amherst, MA 01003. Phone: 413-545-9651; Fax: 413-545-1578; email:dlovley@microbio.umass.edu

EDUCATION:

University of Connecticut	B.A.	1971-1975	Biological Sciences
Clark University	M.A.	1976-1978	Biological Sciences
Michigan State University	Ph.D.	1978-1982	Microbiology
Virginia Polytechnic Institute	Postdoctoral	1982-1984	Microbiology

PROFESSIONAL APPOINTMENTS:

1999-Present: Distinguished University Professor, University of Massachusetts
2004-Present: Associate Dean, College of Natural Resources and the Environment
1997-2004: Department Head, Department of Microbiology
1995-1999: Professor, Department of Microbiology, University of Massachusetts
1984-1995: Research Hydrologist (GS-15), Water Resources Division, U.S. Geol. Survey

SYNERGISTIC ACTIVITIES:

Program on Microbe-Electrode Interactions for Japanese Television Show Gatchane 2010

Program and Science Project Development for NPR's "Pulse of the Planet" Kid's Science Challenge 2010-2011

Editorial Boards: *Applied and Environmental Microbiology* 1993-2001; *FEMS Microbiology Ecology* 1993-2000; *Microbial Ecology* 1996-present; *FEMS Microbiology Reviews* 1997-2000; *Environmental Microbiology* 1998-present; *Geobiology* 2003-present; Associate Editor *Anaerobe* 1994-1998, ISME Journal 2007-present; Editor, mBio 2010-present.

Science Committees (examples):

National Research Council Committee on Intrinsic Remediation of Contaminants in Subsurface Environments, 1997-2000

Natural and Accelerated Bioremediation Research (NABIR) subcommittee of the Biological and Environmental Research Advisory Committee, Department of Energy, May 2000-2002

National Academies Steering Committee on Systems Biology, 2003

RECENT AWARDS:

2009: Time Magazine Top Invention of 2009: Electric Microbe
2007: Life Achievement Award, International Conference on Soils, Sediments, and Water
2007: 'Top Cited Author', Environmental Microbiology
2006: Division Q Lecturer, American Society for Microbiology
2006: Top contributors to biotechnology in the last decade, *Nature Biotechnology*
2004: Proctor and Gamble Award in Applied and Environmental Microbiology
2003-Present: Most Highly Cited, Institute for Scientific Information (H factor: 95)

RELEVANT PUBLICATIONS (pdfs available at www.geobacter.org):

Bond, D.R., D.E. Holmes, L.M. Tender, D.R. Lovley. 2002. Electrode-reducing microorganisms that harvest energy from marine sediments. Science 295:483-485.

Bond, D. R., and D. R. Lovley. 2003. Electricity production by *Geobacter sulfurreducens* attached to electrodes. Appl. Environ. Microbiol. 69: 1548-1555.

Chaudhuri, S. K., and D. R. Lovley. 2003. Electricity from direct oxidation of glucose in mediator-less microbial fuel cells. Nature Biotechnol. 21:1229-1232.

Reguera, G., K. D. McCarthy, T. Mehta, J. Nicoll, M. T. Tuominen, and D. R. Lovley. 2005. Extracellular electron transfer via microbial nanowires. Nature 435**:**1098-1101.

Reguera, G., K. P. Nevin, J. S. Nicoll, S. F. Covalla, T. Woodard, and D. R. Lovley. 2006. Biofilm and nanowire production leads to increased current in *Geobacter sulfurreducens* fuel cells. Appl. Environ. Microbiol. 72:7345-7348.

Nevin, K. P., H. Richter, S. F. Covalla, J. P. Johnson, T. L. Woodard, H. Jia, M. Zhang, and D. R. Lovley. 2008. Power output and columbic efficiencies from biofilms of Geobacter sulfurreducens comparable to mixed community microbial fuel cells. Environ. Microbiol.10:2505-2514.

Franks, A.E., K.P. Nevin, H. Jia, M. Izallalen, T.L. Woodard, and D.R. Lovley. 2009. Novel strategy for three-dimensional real-time imaging of microbial fuel cell communities: monitoring the inhibitory effects of proton accumulation within the anode biofilm. Energy Environ Sci 2:113-119.

Nevin, K.P., B.C. Kim, R.H. Glaven, J.P. Johnson, T.L. Woodard, B.A. Methé, R.J. DiDonato, S.F. Covalla, A.E. Franks, A. Liu, and D.R. Lovley. 2009. Anode biofilm transcriptomics reveals outer surface components essential for high density current production in *Geobacter sulfurreducens* fuel cells. PLoS ONE 4:e5628.

Franks, A.E., K.P. Nevin, R.H. Glaven and D.R. Lovley. 2009. Microtoming coupled to microarray analysis to evaluate the spatial metabolic status of *Geobacter sulfurreducens* biofilms. ISME J 4:509-519.

Leang, C., X. Qian, T. Mester, and D.R. Lovley. 2010. Alignment of the c-type cytochrome OmcS along pili of Geobacter sulfurreducens.. Appl. Environ. Microbiol. 76:4080-4084.

Inoue, K., C. Leang, A. E. Franks, T. L. Woodard, K. P. Nevin, and D. R. Lovley. 2011. Specific localization of the *c*-type cytochrome OmcZ at the anode surface in current-producing biofilms of *Geobacter sulfurreducens*. Environ. Microbiol. Rep. 3:211-217.

Yi, H., K. P. Nevin, B.-C. Kim, A. E. Franks, A. Klimes, L. M. Tender, and D. R. Lovley. 2009. Selection of a variant of *Geobacter sulfurreducens* with enhanced capacity for current production in microbial fuel cells. Biosensors Bioelectron. 24:3498-3503.

Summers, Z. M., H. Fogarty, C. Leang, A. E. Franks, N. S. Malvankar, and D. R. Lovley. 2010. Cooperative exchange of electrons within aggregates of an evolved syntrophic co-culture. Science 330:1413-1415.

Malvankar, N.S., M. Vargas, K.P. Nevin, A.E. Franks, C. Leang, B-C. Kim, K. Inoue, T. Mester, S.F. Covalla, J.P. Johnson, V.M. Rotello, M.T. Tuominen, and D.R. Lovley. 2011. Tunable metallic-like conductivity in microbial nanowire networks. Nature Nanotechnology 6: 573-579.

RELEVANT PATENT:

Microbial Nanowires, Patent No. 7,498,155

Biographical Sketch-Nikhil S. Malvankar

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EDUCATION:

University of Massachusetts, Amherst	Ph.D.	2010	Physics
University of Massachusetts, Amherst	M.S.	2010	Physics
Indian Institute of Technology, Bombay, India	M.Sc.	2003	Physics
University of Mumbai, India	B.Sc.	2001	Physics

PROFESSIONAL APPOINTMENTS:
2010 – Present: Postdoctoral Research Associate, University of Massachusetts, Amherst

PROFESSIONAL ASSOCIATIONS AND ACTIVITIES:
American Physical society, member 2009-2012
American Chemical society, member 2010-2011
American Society of Microbiology, member 2008-2010
Microscopy Society, member, 2011-2012
Post-graduate member of the search committee for condensed matter physics faculty 2011.
Graduate student member of the search committee for biophysics faculty 2008.
Reviewer for Nature Nanotechnology, Nature Geoscience, Environmental Science and Technology

RECENT AWARDS:
Biophysics research award – 2009
Second prize ($25K) in Innovation Challenge Business Plan Competition - 2009
Scholarship for Advanced Invention to Venture workshop - 2009
First prize ($4K) in Innovation Challenge Elevator Pitch Competition - 2008
Isenberg award for integration of science, engineering and management 2008-2009.

RELEVANT PUBLICATIONS AND PRESENTATIONS:
Nikhil S. Malvankar, Madeline Vargas , K.P.Nevin, A. E. Franks, Ching Leang, B.C. Kim, Kengo Inoue, Tünde Mester, S. F. Covalla, J. P. Johnson, V.M. Rotello, M. T. Tuominen, and D. R. Lovley. Tunable metallic-like conductivity in nanostructured biofilm associated with microbial nanowires. Nature Nanotechnology 6 (9), 573-579 (2011)

Morita, M., Malvankar, N.S., Franks, A.E., Summers, Z.M., Giloteaux, L., Rotaru, A.E., Rotaru, C., & Lovley, D.R., Potential for Direct Interspecies Electron Transfer in Methanogenic Wastewater Digester Aggregates. mBio 2 (4), e00159-00111 (2011).

Z. M. Summers, Heather Fogarty, Ching Leang, A. E. Franks, Nikhil S.Malvankar, and D.R. Lovley Cooperative Exchange of Electrons Within Aggregates of an Evolved Syntrophic Co-Culture. Science. 330, 1413-1415 (2010).

Debabrata Patra, Nikhil S. Malvankar, Erica Chin, Mark Tuominen, Zhiyong Gu, and

Vincent M. Rotello. Fabrication of conductive microcapsules via self-assembly and crosslinking of gold nanowires at liquid–liquid interfaces. Small, 6: 1402–1405. doi: 10.1002/smll.200902380 (2010)

A. E. Franks, Nikhil S. Malvankar, K.P.Nevin. Bacterial biofilms: the powerhouse of a microbial fuel cell. Biofuels 1(4):589-604 (2010)

Nikhil S. Malvankar, Madeline Vargas, Mark T. Tuominen and Derek R. Lovley. Metallic-like long range electron conduction along pilA pili of Geobacter sulfurreducens. DOE Subsurface Biogeochemical Research contractor-grantee workshop, Washington D.C, 27 April 2011

Nikhil S. Malvankar, Madeline Vargas, M. T. Tuominen, and D. R. Lovley. Experimental observation of very large magnetoconductance in microbial nanowires. American Physical Society Meeting, March 2011, Dallas, TX. Abstract #X30.00005

Nikhil S. Malvankar, Kelly P. Nevin, Caroline Reynolds, Tünde Mester, Mark T. Tuominen and Derek R. Lovley. Demonstration of Biofilm Conductivity Regulates Microbial Fuel Cell Current Density and Cytochromes Acts as Capacitors. North Americal bio-electric systems meeting, October 2010, Amherst, MA

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Madeline Vargas, Kengo Inoue, Tunde Mester, M. T. Tuominen, and D. R. Lovley. Investigations of mechanisms of extracellular electron transfer in anode biofilms of Geobacter sulfurreducens. American Chemical Society national meeting, March 2010, San Francisco CA.

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Madeline Vargas, Kengo Inoue, M. T. Tuominen, and D. R. Lovley. Experimental studies of charge transport and storage in microbial biofilms. American Physical SocietyMeeting, March 2010, Portland OR. Abstract #Q16.008

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Ching Leang, M. T. Tuominen, and D. R. Lovley. Tuning the conductivity and capacitance of Geobacter sulfurreducens biofilms by regulation of gene expression. DOE Genomic Science meeting and Knowledgebase workshop, February 2010, Crystal City, VA

Nikhil S. Malvankar. Unusual electron transfer and storage in microbial biofilms, University of Massachusetts Microbiology department seminar, February 2010. (Invited talk).

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Ching Leang, M. T. Tuominen, and D. R. Lovley. Increased biofilm conductivity associated with higher current density in anode biofilms of Geobacter sulfurreducens. American Society of microbiology conference 2009, Philadelphia, PA

Nikhil Malvankar, K. P. Nevin, S. F. Covalla, J. P. Johnson, A. E. Franks, V. M. Rotello, M. T. Tuominen, and D. R. Lovley. Direct Measurements of Electrical Conductance of Geobacter sulfurreducens Biofilms in Microbial Fuel Cells. American Society of microbiology conference 2008, Boston MA. Poster Q-388.

Nikhil Malvankar, N.Venkataramani, Shiva Prasad, R.P.R.C. Aiyar and R. Krishnan, Study of Kerr effect in magnetic thin films and multilayers, National Symposium of Instrumentation, Instrument Society of India, November 2003.

Derek R. Lovley Funding Support

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Current Support:

Genome–Based Models to Optimize *In Situ* Bioremediation of Uranium and Harvesting Electrical Energy from Waste Organic Matter.
U.S. Department of Energy
Aug 2005 - Aug 2012 5 months effort $21,759,997
Univ. of MA Amherst (Prime)
Genomatica Inc., TIGR(JCVI), Univ of TN, UCSD, U Toronto, Argonne National Laboratories (subcontracts)

Electrodes as an Electron Acceptor to Accelerate the Microbial Degradation of Organic Contaminants in Marine Sediments
Office of Naval Research
October 2008-October 2011 0.5 months effort $384,023
Univ. of MA Amherst (Prime)

Mechanisms for Electron Transfer through Electrochemically Active Biofilms
Office of Naval Research
October 2009-September 2012 0.75 months effort $621,508
Univ. of MA Amherst (Prime)

Coupled *In Silico* Microbial and Geochemical Reactive Transport Models: Extension to Multi-Organism Communities, Upscaling and Experimental Validation
U.S Department of Energy
May 2010 – May 2013 0.5 months effort $995,147
Univ. of MA Amherst (Prime), Univ of Toronto (subcontract)

Mechanisms for Electron Transfer Through Pili to Fe(III) Oxide in Geobacter
U.S Department of Energy
June 2010 – May 2013 0.5 months effort $814,534
Univ. of MA Amherst (Prime)

Systems Level Analysis of the Function and Adaptive Responses of Methanogenic Consortia
U.S Department of Energy
August 2010 – July 2013 1.5 months effort $2,294,069
Univ. of MA Amherst (Prime), UCSD (Subcontract)

Diagnosis of *In Situ* Metabolic State and Rates of Microbial Metabolism During *In Situ* Uranium Bioremediation with Molecular Techniques
U.S Department of Energy
June 2010 – May 2012 0.5 months effort $471,006
Univ. of MA Amherst (Prime)

Electrofuels via Direct Electron Transfer from Electrodes to Microbes
U.S Department of Energy: Advanced Research Projects Agency - Energy
July 2010 – August 2012 2.5 months effort $1,668,000
Univ. of MA Amherst (Prime), UCSD (Subcontract)

Microbial Fuel Cell for Distributed Seafloor Sensor Network Powering.
Scribner Associates Inc. ONR STTR Phase II
May 2010 – November 2011 0.5 months effort $748,829
Univ. of MA Amherst (Prime)

Electrofuels via Direct Electron Transfer from Electrodes to Microbes II
U.S Department of Energy: Advanced Research Projects Agency - Energy
January 2011 – December 2011 3 months effort $1,800,000
Univ. of MA Amherst (Prime), Genomatica (Subcontract)

Real Time Monitoring of Rates of Subsurface Microbial Activity Associated with Natural Attenuation and Electron Donor Availability for Engineered Bioremediation with Current-Producing Microorganisms
U.S Department of Energy
September 2011 – August 2014 0.5 months effort $1,212,981
Univ. of MA Amherst (Prime), LBNL (Subcontract)

Pending Support:

Electrofuels via Direct Electron Transfer from Electrodes to Microbes II (continuation)
U.S Department of Energy: Advanced Research Projects Agency - Energy
January 2012 – June 2013 | 4 months effort | $2,500,000
Univ. of MA Amherst (Prime), Genomatica (Subcontract)

Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires
Office of Naval Research
January 2012 - December 2014 | 0.75 months effort | $653,657
Univ. of MA Amherst (Prime)

Nikhil Malvankar Funding Support
University of Massachusetts, Amherst

Technical Contact:
Nikhil Malvankar
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Department of Microbiology
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Administrative/Business Contact:
Carol Sprague, Director
Grants and Contract Administration
Research Administration Building
70 Butterfield Terrace
U of MA, Amherst, MA 01003
Phone: (413)545-0698
FAX: (413)545-1202
Email: sprague@research.umass.edu

Current Support:
None

Pending Support:
Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires
Office of Naval Research
January 2012 - December 2014 0.75 months effort $653,657
Univ. of MA Amherst (Prime)

BUDGET JUSTIFICATION
Office of Naval Research BAA 11-001
University of Massachusetts

Overall Budget:
Year 1 (1/1/12 - 9/30/12): $146,700
Year 2 (10/1/12 - 9/30/13): $209,944
Year 3 (10/1/13 - 9/30/14): $216,242
Year 4 (10/1/14 - 12/31/14): $65,463
Total Funding (1/1/12 - 12/31/14): $638,349

Personnel:
Funds are requested for 0.75 months academic salary each calendar year for the principal investigator to coordinate experimental approaches and to prepare reports and peer-reviewed articles for the project. ((b) (4) total funding including 3% COLA each year)
Rate is based on current salary and 3% COLA each year.

Funds are requested for 6 calendar months salary each calendar year for the co-principal investigator to develop novel aspects of the experimental approaches and carry out those experiments requiring substantial prior experience with nanowire experimentation including conductivity and microscopic analysis. (b) (4) total funding including 3% COLA each year)
Rate is based on current salary and 3% COLA each year.

Funds are further requested for one part-time (6 calendar months each calendar year) postdoctoral research associate to conduct genetics studies and other aspects of the research. ((b) (4) total funding including 3% COLA each year)
Rate is based on current NIH standards and 3% COLA each year.

Fringe Rates:
Faculty PI ((b) (4) total funding):
Fringe = 32.98%
Workers Compensation = 0.38%
Unemployment, Universal Health, MTX (Medicare tax) = 1.94%
Health and Welfare = $14/week

Postdoctoral Co-PI and Postdoctoral Fellow ((b) (4) total funding/person):
Workers Compensation = 0.38%
Unemployment, Universal Health, MTX (Medicare tax) = 1.94%

Rates are based on current negotiated and approved rates.
http://www.umass.edu/research/system/files/FACTSHT2.pdf

Health Insurance:

Postdoctoral Fellow Health Insurance Plan = $278/month (September-August)
Rate is based on current negotiated cost.

http://www.umass.edu/research/system/files/FACTSHT2.pdf

Travel:

Funds are requested for travel to collaborators for experiments ($1000/person/trip), National Microbiology meetings to present data ($2000/person/trip), and Washington DC for ONR meetings ($1000/person/trip). Rate is based on previous experience with purchases for similar travel with 3% inflation rate.

Publications:

Funds are requested for publication costs ($2000/article) in peer-reviewed journals each calendar year. Rate is based on previous experience with purchases for similar publications with 3% inflation rate.

Materials and Supplies:

Funds for materials and supplies requested at an approximate rate of $25,000 per 100% effort researcher for each calendar year. Rate is based on previous experience with purchases for similar research projects with 3% inflation rate.

Materials and Supplies details:

Supply Items include: Custom glassware; electrodes; anode and cathode graphite materials; selective membranes; wires, connectors and resistors; gasket materials; gassing station components: swage fittings, flow meters, pressure gauges; reagents for analytical and electrochemical analysis; gases for anaerobic culturing and fuel cells.

Transmission electron microscopy supplies including: labeled antibodies, support film/grids and electron microscopy use, probes for thermopower and high-frequency measurements; tips for electrostatic force microscopy; liquid helium and liquid nitrogen; specific fluorophores; miscellaneous reagents for molecular, analytical, electrochemical analyses.

Molecular Biology reagents and supplies: acidic phenol, isopropanol, ethanol, isoamyl alcohol/chloroform, TE saturated phenol, linear acrylamide; Superase-In, Proteinase K, lysozyme, yeast tRNA, glycogen, Rneasy mini kits; RNA isolation aid kit; DNA-free kit; reverse transcriptase, restriction enzymes, primers, taq DNA polymerase, dNTPs; PCR primers; TOPO vector cloning kits; microarray supplies including RNA amplification kit and slide chips;

DNA sequencing supplies including Big Dye terminator kit, POP7 polymer

General laboratory reagents, supplies, and small equipment: gases for anaerobic glove bags, anaerobic culturing stations, and bench-top manipulations; columns and reagents for HPLC and ion and gas chromatographs; reagents for protein assays, disposable syringes, needles, pipette tips, filters, tubes, gloves, culturing tubes, butyl rubber stoppers, media ingredients; cell counting supplies and microscope supplies.

Indirect costs:
58.5% of total direct costs for 1/1/12-6/30/12
59.0% of total direct costs for 7/1/12-12/31/14

Rates are based on current negotiated and approved rates.
http://www.umass.edu/research/system/files/FACTSHT2.pdf

Further details will be supplied if requested

CLARIFICATIONS TO ONR BAA-11-001

Submittal of this proposal is based on the understanding that the University of Massachusetts will be conducting Fundamental Research and the resultant work will become part of the public domain. This type of activity is exempt from ITAR per 22 CFR 120.11 Section (a) Item (8), FAR 27.404(a) as implemented by NSDD Rule 189.

The University requests that the work be performed under the terms of a grant or cooperative agreement. If a contract is used, do not pass down Export Controlled materials. The contract will include FAR 52.227-11 Patents, FAR 52.227-14, Alt IV Data Rights and FAR 52.249-5 Termination for Convenience.

1. Section I, Section 11. Other Information, Page 13
Section II, Award Administration Information, Page 14

The University does not have a Security Clearance. The proposal offered by the University is solely intended for unclassified work.

It is the policy of the University to undertake only those research projects in which the purpose, scope, methods, and results can be fully and freely disclosed. As such, any restrictions to publishing the results of the project should be deleted.

RESEARCH & RELATED Senior/Key Person Profile

PROFILE - Project Director/Principal Investigator

Prefix: Dr. | * First Name: Derek | Middle Name: R
* Last Name: Lovley | Suffix:
Position/Title: Professor | Department: Microbiology
Organization Name: University of Massachusetts Amherst | Division:
* Street1: 203N Morrill IVN
Street2: 639 North Pleasant St
* City: Amherst | County: Hampshire
* State: MA: Massachusetts | Province:
* Country: USA: UNITED STATES | * Zip / Postal Code: 01003-9298
* Phone Number: 413-545-9651 | Fax Number: 413-577-4660
* E-Mail: dlovley@microbio.umass.edu

Credential, e.g., agency login:

*** Project Role:** PD/PI | **Other Project Role Category:**

***Attach Biographical Sketch** Lovley Biosketch.pdf | Add Attachment | Delete Attachment | View Attachment

Attach Current & Pending Support DRL_Current and Pending fundi | Add Attachment | Delete Attachment | View Attachment

PROFILE - Senior/Key Person 1

Prefix: Dr. | * First Name: Nikhil | Middle Name:
* Last Name: Malvankar | Suffix:
Position/Title: | Department: Microbiology
Organization Name: University of Massachusetts | Division:
* Street1: 203N Morrill IVN
Street2: 639 North Pleasant St
* City: Amherst | County:
* State: MA: Massachusetts | Province:
* Country: USA: UNITED STATES | * Zip / Postal Code: 01003-9298
* Phone Number: 413-577-1391 | Fax Number: 413-577-4660
* E-Mail: nikhil@physics.umass.edu

Credential, e.g., agency login:

*** Project Role:** Co-PD/PI | **Other Project Role Category:**

***Attach Biographical Sketch** Nikhil Malvankar_CV.pdf | Add Attachment | Delete Attachment | View Attachment

Attach Current & Pending Support NM_Current and Pending fundin | Add Attachment | Delete Attachment | View Attachment

ADDITIONAL SENIOR/KEY PERSON PROFILE(S) | Add Attachment | Delete Attachment | View Attachment

Additional Biographical Sketch(es) (Senior/Key Person) | Add Attachment | Delete Attachment | View Attachment

Additional Current and Pending Support(s) | Add Attachment | Delete Attachment | View Attachment

OMB Number: 4040-0001
Expiration Date: 04/30/2008

Biographical Sketch-Nikhil S. Malvankar

Department of Microbiology, University of Massachusetts, Amherst
Tel: (413) 313-3179 Fax: (413) 577-4660 Email: nikhl@physics.umass.edu

EDUCATION:

University of Massachusetts, Amherst	Ph.D.	2010	Physics
University of Massachusetts, Amherst	M.S.	2010	Physics
Indian Institute of Technology, Bombay, India	M.Sc.	2003	Physics
University of Mumbai, India	B.Sc.	2001	Physics

PROFESSIONAL APPOINTMENTS:
2010 – Present: Postdoctoral Research Associate, University of Massachusetts, Amherst

PROFESSIONAL ASSOCIATIONS AND ACTIVITIES:
American Physical society, member 2009-2012
American Chemical society, member 2010-2011
American Society of Microbiology, member 2008-2010
Microscopy Society, member, 2011-2012
Post-graduate member of the search committee for condensed matter physics faculty 2011.
Graduate student member of the search committee for biophysics faculty 2008.
Reviewer for Nature Nanotechnology, Nature Geoscience, Environmental Science and Technology

RECENT AWARDS:
Biophysics research award – 2009
Second prize ($25K) in Innovation Challenge Business Plan Competition - 2009
Scholarship for Advanced Invention to Venture workshop - 2009
First prize ($4K) in Innovation Challenge Elevator Pitch Competition - 2008
Isenberg award for integration of science, engineering and management 2008-2009.

RELEVANT PUBLICATIONS AND PRESENTATIONS:
Nikhil S. Malvankar, Madeline Vargas , K.P.Nevin, A. E. Franks, Ching Leang, B.C. Kim, Kengo Inoue, Tünde Mester, S. F. Covalla, J. P. Johnson, V.M. Rotello, M. T. Tuominen, and D. R. Lovley. Tunable metallic-like conductivity in nanostructured biofilm associated with microbial nanowires. Nature Nanotechnology 6 (9), 573-579 (2011)

Morita, M., Malvankar, N.S., Franks, A.E., Summers, Z.M., Giloteaux, L., Rotaru, A.E., Rotaru, C., & Lovley, D.R., Potential for Direct Interspecies Electron Transfer in Methanogenic Wastewater Digester Aggregates. mBio 2 (4), e00159-00111 (2011).

Z. M. Summers, Heather Fogarty, Ching Leang, A. E. Franks, Nikhil S.Malvankar, and D.R. Lovley Cooperative Exchange of Electrons Within Aggregates of an Evolved Syntrophic Co-Culture. Science. 330, 1413-1415 (2010).

Debabrata Patra, Nikhil S. Malvankar, Erica Chin, Mark Tuominen, Zhiyong Gu, and

Vincent M. Rotello. Fabrication of conductive microcapsules via self-assembly and crosslinking of gold nanowires at liquid–liquid interfaces. Small, 6: 1402–1405. doi: 10.1002/smll.200902380 (2010)

A. E. Franks, Nikhil S. Malvankar, K.P.Nevin. Bacterial biofilms: the powerhouse of a microbial fuel cell. Biofuels 1(4):589-604 (2010)

Nikhil S. Malvankar, Madeline Vargas, Mark T. Tuominen and Derek R. Lovley. Metallic-like long range electron conduction along pilA pili of Geobacter sulfurreducens. DOE Subsurface Biogeochemical Research contractor-grantee workshop, Washington D.C, 27 April 2011

Nikhil S. Malvankar, Madeline Vargas, M. T. Tuominen, and D. R. Lovley. Experimental observation of very large magnetoconductance in microbial nanowires. American Physical Society Meeting, March 2011, Dallas, TX. Abstract #X30.00005

Nikhil S. Malvankar, Kelly P. Nevin, Caroline Reynolds, Tünde Mester, Mark T. Tuominen and Derek R. Lovley. Demonstration of Biofilm Conductivity Regulates Microbial Fuel Cell Current Density and Cytochromes Acts as Capacitors. North Americal bio-electric systems meeting, October 2010, Amherst, MA

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Madeline Vargas, Kengo Inoue, Tunde Mester, M. T. Tuominen, and D. R. Lovley. Investigations of mechanisms of extracellular electron transfer in anode biofilms of Geobacter sulfurreducens. American Chemical Society national meeting, March 2010, San Francisco CA.

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Madeline Vargas, Kengo Inoue, M. T. Tuominen, and D. R. Lovley. Experimental studies of charge transport and storage in microbial biofilms. American Physical SocietyMeeting, March 2010, Portland OR. Abstract #Q16.008

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Ching Leang, M. T. Tuominen, and D. R. Lovley. Tuning the conductivity and capacitance of Geobacter sulfurreducens biofilms by regulation of gene expression. DOE Genomic Science meeting and Knowledgebase workshop, February 2010, Crystal City, VA

Nikhil S. Malvankar. Unusual electron transfer and storage in microbial biofilms, University of Massachusetts Microbiology department seminar, February 2010. (Invited talk).

Nikhil S. Malvankar, K.P.Nevin, A. E. Franks, Ching Leang, M. T. Tuominen, and D. R. Lovley. Increased biofilm conductivity associated with higher current density in anode biofilms of Geobacter sulfurreducens. American Society of microbiology conference 2009, Philadelphia, PA

Nikhil Malvankar, K. P. Nevin, S. F. Covalla, J. P. Johnson, A. E. Franks, V. M. Rotello, M. T. Tuominen, and D. R. Lovley. Direct Measurements of Electrical Conductance of Geobacter sulfurreducens Biofilms in Microbial Fuel Cells. American Society of microbiology conference 2008, Boston MA. Poster Q-388.

Nikhil Malvankar, N.Venkataramani, Shiva Prasad, R.P.R.C. Aiyar and R. Krishnan, Study of Kerr effect in magnetic thin films and multilayers, National Symposium of Instrumentation, Instrument Society of India, November 2003.

Nikhil Malvankar Funding Support
University of Massachusetts, Amherst

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Phone: (413)545-0698
FAX: (413)545-1202
Email: sprague@research.umass.edu

Current Support:
None

Pending Support:
Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires
Office of Naval Research
January 2012 - December 2014 0.75 months effort $653,657
Univ. of MA Amherst (Prime)

Biographical Sketch-Derek R. Lovley

Department of Microbiology, University of Massachusetts, Amherst, MA 01003. Phone: 413-545-9651; Fax: 413-545-1578; email:dlovley@microbio.umass.edu

EDUCATION:

University of Connecticut	B.A.	1971-1975	Biological Sciences
Clark University	M.A.	1976-1978	Biological Sciences
Michigan State University	Ph.D.	1978-1982	Microbiology
Virginia Polytechnic Institute	Postdoctoral	1982-1984	Microbiology

PROFESSIONAL APPOINTMENTS:

1999-Present: Distinguished University Professor, University of Massachusetts
2004-Present: Associate Dean, College of Natural Resources and the Environment
1997-2004: Department Head, Department of Microbiology
1995-1999: Professor, Department of Microbiology, University of Massachusetts
1984-1995: Research Hydrologist (GS-15), Water Resources Division, U.S. Geol. Survey

SYNERGISTIC ACTIVITIES:

Program on Microbe-Electrode Interactions for Japanese Television Show Gatchane 2010

Program and Science Project Development for NPR's "Pulse of the Planet" Kid's Science Challenge 2010-2011

Editorial Boards: *Applied and Environmental Microbiology* 1993-2001; *FEMS Microbiology Ecology* 1993-2000; *Microbial Ecology* 1996-present; *FEMS Microbiology Reviews* 1997-2000; *Environmental Microbiology* 1998-present; *Geobiology* 2003-present; Associate Editor *Anaerobe* 1994-1998, ISME Journal 2007-present; Editor, mBio 2010-present.

Science Committees (examples):

National Research Council Committee on Intrinsic Remediation of Contaminants in Subsurface Environments, 1997-2000

Natural and Accelerated Bioremediation Research (NABIR) subcommittee of the Biological and Environmental Research Advisory Committee, Department of Energy, May 2000-2002

National Academies Steering Committee on Systems Biology, 2003

RECENT AWARDS:

2009: Time Magazine Top Invention of 2009: Electric Microbe
2007: Life Achievement Award, International Conference on Soils, Sediments, and Water
2007: 'Top Cited Author', Environmental Microbiology
2006: Division Q Lecturer, American Society for Microbiology
2006: Top contributors to biotechnology in the last decade, *Nature Biotechnology*
2004: Proctor and Gamble Award in Applied and Environmental Microbiology
2003-Present: Most Highly Cited, Institute for Scientific Information (H factor: 95)

RELEVANT PUBLICATIONS (pdfs available at www.geobacter.org):

Bond, D.R., D.E. Holmes, L.M. Tender, D.R. Lovley. 2002. Electrode-reducing microorganisms that harvest energy from marine sediments. Science 295:483-485.

Bond, D. R., and D. R. Lovley. 2003. Electricity production by *Geobacter sulfurreducens* attached to electrodes. Appl. Environ. Microbiol. 69: 1548-1555.

Chaudhuri, S. K., and D. R. Lovley. 2003. Electricity from direct oxidation of glucose in mediator-less microbial fuel cells. Nature Biotechnol. 21:1229-1232.

Reguera, G., K. D. McCarthy, T. Mehta, J. Nicoll, M. T. Tuominen, and D. R. Lovley. 2005. Extracellular electron transfer via microbial nanowires. Nature 435**:**1098-1101.

Reguera, G., K. P. Nevin, J. S. Nicoll, S. F. Covalla, T. Woodard, and D. R. Lovley. 2006. Biofilm and nanowire production leads to increased current in *Geobacter sulfurreducens* fuel cells. Appl. Environ. Microbiol. 72:7345-7348.

Nevin, K. P., H. Richter, S. F. Covalla, J. P. Johnson, T. L. Woodard, H. Jia, M. Zhang, and D. R. Lovley. 2008. Power output and columbic efficiencies from biofilms of Geobacter sulfurreducens comparable to mixed community microbial fuel cells. Environ. Microbiol.10:2505-2514.

Franks, A.E., K.P. Nevin, H. Jia, M. Izallalen, T.L. Woodard, and D.R. Lovley. 2009. Novel strategy for three-dimensional real-time imaging of microbial fuel cell communities: monitoring the inhibitory effects of proton accumulation within the anode biofilm. Energy Environ Sci 2:113-119.

Nevin, K.P., B.C. Kim, R.H. Glaven, J.P. Johnson, T.L. Woodard, B.A. Methé, R.J. DiDonato, S.F. Covalla, A.E. Franks, A. Liu, and D.R. Lovley. 2009. Anode biofilm transcriptomics reveals outer surface components essential for high density current production in *Geobacter sulfurreducens* fuel cells. PLoS ONE 4:e5628.

Franks, A.E., K.P. Nevin, R.H. Glaven and D.R. Lovley. 2009. Microtoming coupled to microarray analysis to evaluate the spatial metabolic status of *Geobacter sulfurreducens* biofilms. ISME J 4:509-519.

Leang, C., X. Qian, T. Mester, and D.R. Lovley. 2010. Alignment of the c-type cytochrome OmcS along pili of Geobacter sulfurreducens.. Appl. Environ. Microbiol. 76:4080-4084.

Inoue, K., C. Leang, A. E. Franks, T. L. Woodard, K. P. Nevin, and D. R. Lovley. 2011. Specific localization of the *c*-type cytochrome OmcZ at the anode surface in current-producing biofilms of *Geobacter sulfurreducens*. Environ. Microbiol. Rep. 3:211-217.

Yi, H., K. P. Nevin, B.-C. Kim, A. E. Franks, A. Klimes, L. M. Tender, and D. R. Lovley. 2009. Selection of a variant of *Geobacter sulfurreducens* with enhanced capacity for current production in microbial fuel cells. Biosensors Bioelectron. 24:3498-3503.

Summers, Z. M., H. Fogarty, C. Leang, A. E. Franks, N. S. Malvankar, and D. R. Lovley. 2010. Cooperative exchange of electrons within aggregates of an evolved syntrophic co-culture. Science 330:1413-1415.

Malvankar, N.S., M. Vargas, K.P. Nevin, A.E. Franks, C. Leang, B-C. Kim, K. Inoue, T. Mester, S.F. Covalla, J.P. Johnson, V.M. Rotello, M.T. Tuominen, and D.R. Lovley. 2011. Tunable metallic-like conductivity in microbial nanowire networks. Nature Nanotechnology 6: 573-579.

RELEVANT PATENT:

Microbial Nanowires, Patent No. 7,498,155

Derek R. Lovley Funding Support
University of Massachusetts, Amherst

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Administrative/Business Contact:
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Research Administration Building
70 Butterfield Terrace
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Phone: (413)545-0698
FAX: (413)545-1202
Email: sprague@research.umass.edu

Current Support:
Genome–Based Models to Optimize *In Situ* Bioremediation of Uranium and Harvesting Electrical Energy from Waste Organic Matter.
U.S. Department of Energy
Aug 2005 - Aug 2012 5 months effort $21,759,997
Univ. of MA Amherst (Prime)
Genomatica Inc., TIGR(JCVI), Univ of TN, UCSD, U Toronto, Argonne National Laboratories (subcontracts)

Electrodes as an Electron Acceptor to Accelerate the Microbial Degradation of Organic Contaminants in Marine Sediments
Office of Naval Research
October 2008-October 2011 0.5 months effort $384,023
Univ. of MA Amherst (Prime)

Mechanisms for Electron Transfer through Electrochemically Active Biofilms
Office of Naval Research
October 2009-September 2012 0.75 months effort $621,508
Univ. of MA Amherst (Prime)

Coupled *In Silico* Microbial and Geochemical Reactive Transport Models: Extension to Multi-Organism Communities, Upscaling and Experimental Validation
U.S Department of Energy
May 2010 – May 2013 0.5 months effort $995,147
Univ. of MA Amherst (Prime), Univ of Toronto (subcontract)

Mechanisms for Electron Transfer Through Pili to Fe(III) Oxide in Geobacter
U.S Department of Energy
June 2010 – May 2013 0.5 months effort $814,534
Univ. of MA Amherst (Prime)

Systems Level Analysis of the Function and Adaptive Responses of Methanogenic Consortia
U.S Department of Energy
August 2010 – July 2013 1.5 months effort $2,294,069
Univ. of MA Amherst (Prime), UCSD (Subcontract)

Diagnosis of *In Situ* Metabolic State and Rates of Microbial Metabolism During *In Situ* Uranium Bioremediation with Molecular Techniques
U.S Department of Energy
June 2010 – May 2012 0.5 months effort $471,006
Univ. of MA Amherst (Prime)

Electrofuels via Direct Electron Transfer from Electrodes to Microbes
U.S Department of Energy: Advanced Research Projects Agency - Energy
July 2010 – August 2012 2.5 months effort $1,668,000
Univ. of MA Amherst (Prime), UCSD (Subcontract)

Microbial Fuel Cell for Distributed Seafloor Sensor Network Powering.
Scribner Associates Inc. ONR STTR Phase II
May 2010 – November 2011 0.5 months effort $748,829
Univ. of MA Amherst (Prime)

Electrofuels via Direct Electron Transfer from Electrodes to Microbes II
U.S Department of Energy: Advanced Research Projects Agency - Energy
January 2011 – December 2011 3 months effort $1,800,000
Univ. of MA Amherst (Prime), Genomatica (Subcontract)

Real Time Monitoring of Rates of Subsurface Microbial Activity Associated with Natural Attenuation and Electron Donor Availability for Engineered Bioremediation with Current-Producing Microorganisms
U.S Department of Energy
September 2011 – August 2014 0.5 months effort $1,212,981
Univ. of MA Amherst (Prime), LBNL (Subcontract)

Pending Support:

Electrofuels via Direct Electron Transfer from Electrodes to Microbes II (continuation)
U.S Department of Energy: Advanced Research Projects Agency - Energy
January 2012 – June 2013 4 months effort $2,500,000
Univ. of MA Amherst (Prime), Genomatica (Subcontract)

Mechanisms Underlying the Metallic-Like Conductivity of Microbial Nanowires
Office of Naval Research
January 2012 - December 2014 0.75 months effort $653,657
Univ. of MA Amherst (Prime)